Doctoral Thesis

Fostering the development and introduction of new technologies – insights from multiple stakeholder perspectives

Author(s):
Wu, Geng

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Fostering the development and introduction of new technologies – insights from multiple stakeholder perspectives

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presented by
GENG WU,
M.A. University of St. Gallen
born on 20.10.1985
citizen of Germany

accepted on the recommendation of
Examiner: Prof. Dr. Volker Hoffmann
Co-examiner: Prof. Dr. Timo Busch
2016
I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

Isaac Newton
Acknowledgements

Ironically, the acknowledgement section is placed at the beginning of the dissertation, but was written at the end of my academic journey. Hence, I consider this section as my own concluding reflection on my PhD study. Looking back, I feel grateful for so many gifts my study provided me such as the people I could get to know, the research contents I could work on, and the everyday academic life I could enjoy. Here, I want to specifically thank the people who supported me the most during the time of my PhD study.

First and foremost, I want to express my gratitude to my supervisor, Prof. Dr. Volker Hoffmann, who was a caring mentor, challenging sparring partner, and an inspiring role model. It is amazing how you are able to provide each researcher the freedom to pursue his own intellectual passion and still be able to form a coherent and supportive group. I personally benefited from this freedom as my initial research field was not established in our group. I also benefited from your intensive involvement in providing me feedback on numerous paper drafts and direct coaching on many occasions. Thank you for caring and believing in me. I also want to thank Prof. Dr. Timo Busch for his time, effort, and passion to be my co-examiner. Although we had little time to work together at the Chair of Sustainability and Technology (SusTec) due to your being called to Hamburg, you have always remained an inspiring discussion partner on many occasions such as at the Gronen Conference in 2014.

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Abstract

In order to counteract the negative effects of global warming, the transition from the current system of energy supply and energy use to a more sustainable system is one of the major challenges for the global society today. In this, the introduction of new technologies that avoid or reduce environmental damage, is one way to reduce greenhouse gas emissions as a cause of global warming and to sustain economic growth. However, the determinants of development and diffusion of new technologies are manifold and complex due to the multiple stakeholders involved. Especially for firms as the developers and suppliers of new technologies and for policy makers as their regulating and facilitating institution, challenges arise when other stakeholders such as consumers, NGOs, or the broader public do not act as anticipated.

This dissertation aims to advance our understanding of how policy makers and firms can facilitate the development and introduction of new technologies with consideration of different perspectives of consumers and other stakeholders. Specifically, this dissertation assesses four themes with four papers. The first paper examines the differences in cost efficiency of a technology publicly supported by policy makers across different market segments. The second paper scrutinizes the effect of policy on firm knowledge search behavior. The third paper explores the process and motivation of firms engaged in the legitimation of non-proprietary technologies. Lastly, the fourth paper studies how secondary stakeholders are managed by the firm in order to successfully introduce technological innovations. In this way, these papers draw on theoretical perspectives from consumer choice, organizational learning, institutional entrepreneurship, and stakeholder theory literature.

Since these papers put their focus on different interfaces among firms, policy makers, consumers, and other stakeholders, they also draw on empirical data from multiple cases including electric vehicles (EV), solar photovoltaic (PV), nanotechnology, biodegradable plastics, and genetically modified organisms (GMOs). These cases are appropriate for the assessment of new technologies. Also methodologically, this dissertation applies different research designs to cope with the different perspectives required. Thus, technology-economic modelling and panel data regression are applied as quantitative methods to generate results deductively, whereas case study research is used to inductively develop theories.

The results of this dissertation contribute to the literature in four ways. First, our findings suggest that a firm can gain firm-specific resources contributing to competitive advantage for
its own end product through legitimation of non-proprietary technologies. Second, this dissertation yields insights on the detailed mechanisms of how such competitive benefits can be gained for the entrepreneurial firm. Third, this dissertation further advances our understanding of the effect of policies on firms’ knowledge search. In this, we found evidence that technology-push policies can facilitate distant search outside of the own technological domains. Fourth, this dissertation opens the corporate “black box” and provides insights on how strategic stakeholder management can be conducted during the phases of innovation development.

Several policy and management implications can be derived from this dissertation. Since the cost efficiency of new technologies can vary significantly across market segments, policy measures which nudge consumers towards more case-specific evaluations of the technologies could foster the introduction of the technology. Such an evaluation can help consumers realize whether the new technology is feasible for their respective case. In addition, policy makers should be aware that in addition to technology-push policies, demand-pull policies might also lead to explorative firm knowledge search behavior and thus to the development of radical innovations. For corporate managers, our empirical observations suggest that even the legitimation of non-proprietary technologies can lead to firm-specific benefits. Hence, investing in the legitimation of such technologies might represent an alternative way to gain competitive advantage (as opposed to typical competitive measures). To support this process, managers should proactively develop broad collaboration platforms with other firms (and even competitors) early in the innovation process in order to create the opportunity for a later return from firm-individual practices to cooperative practices. In addition to these contributions and implications, this dissertation discusses further research opportunities.
Zusammenfassung

Um die negativen Auswirkungen der globalen Erwärmung entgegenzuwirken, stellt der Wandel von der aktuellen zu einem mehr nachhaltigen System der Energiebereitstellung- und Nutzung eines der größten Herausforderung für die heutige, globale Gesellschaft dar. Dabei ist die Einführung von neuen Technologien, welche die Umweltschäden verhindern oder reduzieren können, ein Weg, um Treibhausgase, die für die globale Erwärmung verantwortlich sind, zu verringern und zugleich Wirtschaftswachstum zu sichern. Allerdings sind die Einflussfaktoren für die Entwicklung und Einführung von neuen Technologien aufgrund der vielen betroffenen Interessensgruppen vielseitig und komplex. Besonders für Firmen als die Entwickler und Anbieter von neuen Technologien und für politische Entscheidungsträger als die regulierende und fördernde Institution entstehen Herausforderungen, wenn andere Interessensgruppen wie zum Beispiel Konsumenten, NGOs, oder die breite Öffentlichkeit nicht wie erwartet agieren.


als quantitative Methoden zur deduktiven Herleitung von Ergebnissen und Fallstudien als induktive Entwicklung von Theorien eingesetzt.


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1. Introduction

1.1 The general challenge of developing and introducing new technologies

In order to counteract climate change towards increased global warming, the transition from the current system of energy supply and energy use to a more sustainable one is one of the major challenges of the global society (Stocker et al., 2014). This challenge has become more crucial during the past decades since the combination of an increase in energy demand and the greenhouse gas emissions associated with energy provision has been identified as a major cause of the recent climate change. Between 1973 and 2012, the annual global primary energy demand has more than doubled (IEA, 2014). At the same time, energy provision still heavily relies on fossil fuels as approximately 60% of the 2012 global primary energy supply is still achieved with coal and oil (compared to 70% in 1973). To face the challenge of mitigating the negative consequences of climate change, many national regulations (e.g. Clean Energy and Security Act) and international agreements (e.g. Kyoto Protocol) have been initiated.

There is the common understanding that the introduction of new technologies is one lever to fulfill the national and international agreements and to simultaneously sustain economic growth because some of these technologies can avoid or even decrease environmental damage (Horbach, 2008; Jaffe, Newell, & Stavins, 2002; Rosenberg, 1974). However, the determinants of creation and diffusion of new technologies are manifold and complex and require the consideration of multiple perspectives of the supply side, demand side, and policy makers (Horbach, 2008). On the supply side, the technological capabilities of the firm and its capability to appropriate rents from the new technology are decisive determinants. On the demand side, the expected market pull and the awareness and preference of the new technology in the views of the social environment – i.e. various stakeholders directly or indirectly affected by the new technology – are important predictors of the creation and diffusion of new technologies. From the perspective of policy makers, the institutional structure (e.g. existence of networks, organization of information sharing) and policies (e.g. environmental regulations or incentives) can affect both the supply and demand side. Hence, each perspective involves different actors such as the firms on the supply side, the customers and the stakeholders on the demand side, and the policy makers deciding on the incentives and regulations.

In this arena of multiple stakeholders, policy makers and firms face complex challenges in launching new technologies as observed in recent cases. For instance, innovations for renewable
energy production (e.g. through photovoltaics) often still depend on policy subsidies. Similarly, the development of the necessary infrastructure to apply renewable energy (e.g. through electric vehicles) is slower than projected (IEA, 2013). Hence, looking at different perspectives can improve the understanding of how the launch and diffusion of an innovation can be conducted more successfully. This dissertation aims at contributing to such an understanding by scrutinizing the effects and mechanisms of developing and introducing new technologies from the perspective of policy makers and firms. In this, most cases assessed in this dissertation are related to new technologies that avoid or reduce environmental damage.

1.2 The specific challenge for policy makers

In line with national and international climate goals, policy makers have initiated various types of policies to foster the development and market introduction of new technologies that avoid or reduce environmental damage. Large countries such as the United States of America (USA) and Germany exemplify some of the efforts regarding technology-push and demand-pull policies. The USA contributed approximately USD 8 billion in public R&D funding for renewable energies between 2005 and 2014 (Sissine, 2014). During the same time period, Germany spent approximately the same amount of money to refund solar photovoltaic (PV) capacity installations, which was a deployment policy funded through feed-in tariffs (Fraunhofer ISE, 2015). However, it might take a long time for these policies to achieve their desired consequences. For instance, energy generated through PV technology has remained more expensive than conventional energy provision through coal or oil even decades after policy support (Branker, Pathak, & Pearce, 2011). In addition, research has shown that policies have locked out potential technologies which were not commercially competitive at the time of policy introduction (Hoppmann, Peters, Schneider, & Hoffmann, 2013). These policies have one common characteristic. They were applied to the whole (mostly national) market without consideration of the differences in cost efficiency across the different market segments.

Research has shown that policies without a detailed consideration of heterogeneity among market segments and firm behavior might lead to unexpected or even undesired results (Al-Alawi & Bradley, 2013a; Hoppmann et al., 2013). For instance, tax rebates for electric vehicles (EV) might make the new technology more cost-efficient than the incumbent technology for some market segments, but might not change the comparative cost efficiency at all in other segments (Al-Alawi & Bradley, 2013a). Hence, a comparison of the cost efficiency of a new
technology across different market segments can indicate where policies can be designed in a more differentiated or targeted way in order to be more effective. Also, firms respond differently to policies ranging from exploitative to explorative innovation behavior depending on different firm and environmental context factors (Hoppmann et al., 2013; Nemet, 2009). Hence, one objective of this dissertation is to scrutinize 1) the cost efficiency of a new technology for different market segments and 2) the effect of policies on firms which develop and introduce new technologies.

1.3 The specific challenge for firms

The global recognition of the climate change issue and the resulting regulations initiated by policy makers nudge and sometimes even force firms across various industries to develop new technologies that avoid or reduce environmental damage. The German energy transition “Energiewende,” for instance, was an umbrella policy initiative to steer German firms within the energy, transportation, construction, and other industries to participate in the development of environmental technologies in fields such as renewable energy supply, EV, or building insulation (Heinrich Böll Foundation, 2015). The development and introduction of new environmental technologies, however, imply both technological and socio-political challenges for firms. The technological challenges stem from the intensive knowledge and capital stock required to develop the innovation, often requiring substantial firm investments (Horbach, 2008). The socio-political challenges stem from the potentially disruptive and controversial effect of the innovation on stakeholders accustomed to applying incumbent technologies (Hall & Martin, 2005). Hence, it is important to understand how firms can take up this socio-political challenge of legitimizing and introducing new, environmental technologies. The process of legitimizing new technologies has been the focus of scholars in the field of institutional entrepreneurship (e.g. Garud et al. 2002). Institutional entrepreneurship is defined as the process through which agents change institutions out of self-interest (DiMaggio, 1988; Fligstein, 1997).

One form of institutional entrepreneurship is the legitimization of new technologies (Pacheco, York, Dean, & Sarasvathy, 2010). It is well studied why firms engage in legitimization of their proprietary technologies, although the process is associated with high resource commitment (Aldrich & Fiol, 1994; Garud et al., 2002). However, it is less well studied why firms engage in legitimization of non-proprietary technologies such as EV or nanotechnology, despite the dilemma of creating collective goods also available to competitors (cf. Olson 1965). The literature provides first indications that institutional entrepreneurs might gain firm-specific
benefits such as status and reputation or knowledge not available to competitors free-riding on the legitimized technology (Hippel & von Krogh, 2003; Horbach, 2008; Roberts, Hann, & Slaughter, 2006; Von Krogh, Haefliger, Spaeth, & Wallin, 2012; Wasko & Faraj, 2005). However, the literature remains relatively silent about the underlying process – i.e. how these benefits emerge during the process of institutional entrepreneurship. In addition, whereas primary stakeholders (e.g. direct customers, suppliers, own employees, owners) have been the focus of whole management disciplines, the process of managing secondary stakeholders (e.g. media, regulators, broader public) remains less well studied. Such an understanding is important because secondary stakeholders can highly affect the success of innovations (Baron & Hall, 2003; Frooman, 1997; Whysall, 2000). To address these gaps on the firm level, the second objective of this dissertation is to understand 1) how firms can gain competitive benefits in the process of developing and introducing new technologies and 2) how firms manage secondary stakeholders that can influence the development and introduction of new technologies.

1.4 Research framework and overarching research question

Following the research objectives introduced in the previous sections, this dissertation aims to answer the following research question: How can policy makers and firms facilitate the development and introduction of new technologies with consideration of multiple stakeholder perspectives?

![Research framework](image)

**Figure 1.** Research framework

Figure 1 illustrates the research framework of this dissertation. In line with the research question, this dissertation mainly aims at a better understanding how policy support and firm behavior can influence the development and introduction of new technologies through four different
ways. From the perspective of policy makers, I first study how policies supporting an environmental innovation can be more effective by considering the differences in cost efficiency of a new technology across market segments. Subsequently, the effect of policies on firms’ behavior to generate knowledge required for the development of new technologies is examined. From the perspective of the firm, I first scrutinize the motivation and process of developing and introducing new technologies. In addition, a detailed understanding of how firms manage other stakeholders such as NGOs, regulators, or the broader public in order to introduce new technologies is studied. In this, the effects of consumer preferences and stakeholders' actions are essential assumptions underlying my research but are not directly studied. In the following, this manuscript is structured as follows. Section 2 provides an overview of the theoretical background and objectives of the individual papers as well as how these papers contribute to the overall understanding of my research question. Section 3 presents the research case and the different methods for the respective papers. Section 4 provides a synopsis of the main results from each of the papers followed by a discussion of theoretical and practical implications in section 5. Subsequently, I conclude with the limitations of this dissertation and opportunities for further research.

2 Theoretical perspectives and objectives of the individual papers

This section introduces the main papers and their respective theoretical perspectives. Following the research framework described in section 1.4, this dissertation assesses the development and market introduction of new technologies at multiple interlinks among stakeholders. Paper I assesses how the cost efficiency of a new technology varies across different market segments and analyzes whether and how policy makers can increase the effectiveness of policy in supporting the development and introduction of this new technology. Papers II, III, and IV all assess the effect on or the effect of firms. Thereby, paper II scrutinizes the effect of policies on firms’ innovation behavior. Paper III assesses how firms legitimize and introduce new technologies that are not proprietary to them. Lastly, paper IV explains how firms manage secondary stakeholders such as NGOs, regulators, or the broader public in order to facilitate the development and introduction of their new technologies. Figure 2 illustrates how these four papers are integrated in the overall research framework.
To assess the different relationships among these constructs, this dissertation draws on four main literature streams. First, to evaluate the cost efficiency of a technology for different consumer segments supported by policy, I draw on decision criteria suggested in the consumer choice literature (Al-Alawi & Bradley, 2013a). Second, to understand the effect of policies on firms’ behavior, I build on the literature of firm knowledge search, which represents a research stream within the organizational learning literature explaining how firms search for new knowledge in order to innovate (e.g. Katila & Ahuja, 2002; March, 1991; Rosenkopf & Nerkar, 2001). Third, to assess how firms develop and introduce new technologies, this dissertation builds on the theory of institutional entrepreneurship. Fourth, to examine how firms manage secondary stakeholders to launch new technologies, I use concepts provided by stakeholder theory. All these literature streams are introduced in more detail in the next section. Table 1 illustrates the papers contributing to the understanding of the respective interfaces among different stakeholders relevant to this dissertation. In the following, this section presents the theoretical background, research gap and research question for each of the papers.

**Figure 2. Papers within the research framework**
Table 1. Overview of papers in this dissertation

<table>
<thead>
<tr>
<th>Overall research question</th>
<th>Target audience</th>
<th>Papers</th>
<th>Contribution to research question</th>
<th>Research question of the paper</th>
<th>Main underlying literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>How can policy makers and firms facilitate the launch of new technologies with consideration of the perspectives of consumers and other stakeholders?</td>
<td>Policy makers</td>
<td>I</td>
<td>To understand the differences in cost efficiency for different market segments of a new technology supported by policies</td>
<td>How does the total cost of ownership of electric vehicles compare to that of conventional vehicles across the major vehicle classes and driving distance cases?</td>
<td>Consumer choice</td>
</tr>
<tr>
<td>II</td>
<td>To understand the effect of policies on firm’s knowledge search behavior to develop innovations</td>
<td>What is the effect of demand-pull and technology-push policies on firm knowledge search?</td>
<td>Firm knowledge search</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firms</td>
<td>III</td>
<td>To understand the benefits for firms to develop and introduce non-proprietary technologies and the mechanisms of gaining these benefits</td>
<td>How does a firm gain firm-specific benefits from acting as an institutional entrepreneur who champions a non-proprietary technology?</td>
<td>Institutional entrepreneurship</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>To understand the mechanisms firms can use in order to manage secondary stakeholders during development and introduction of innovations</td>
<td>How can firms conduct strategic management of secondary stakeholders along the innovation process of a radical technological innovation?</td>
<td>Stakeholder theory</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1 Paper I: Consumer choice – understanding the differences in cost efficiency of a new technology for different market segments

To assess the difference in cost efficiency of a new technology for different market segments, I draw on the consumer choice literature. This stream of literature mostly applies different criteria to predict the purchase decisions of consumers. In order to find out how policies can be more effective at supporting the development and introduction of new technologies, I build on a specific consumer choice criterion: cost efficiency. In the consumer choice literature, the choice criteria are categorized as utilitarian or hedonic (Dhar & Wertenbroch, 2000). Utilitarian criteria have been qualified as rational and task oriented (Babin, Darden, & Griffin, 1994). Typical utilitarian criteria include usefulness, value, and cost (Batra & Ahtola, 1991; To, Liao, & Lin, 2007). Hedonic criteria have been qualified as emotional and fun-oriented (Babin et al.,
1994). Typical hedonic criteria include pleasantness, agreeability, and fun (Batra & Ahtola, 1991). While both dimensions have been found to be important for the purchase decision of the consumer (Voss, Spangenberg, & Grohmann, 2003), there is evidence that utilitarian criteria such as cost efficiency or use convenience are stronger predictors for the initial purchase (To et al., 2007). Also, hedonic criteria are described as more subjective and personal than utilitarian criteria. Hence, if the technology is new to the market and needs objective evaluation, utilitarian criteria represent adequate initial starting points to predict consumer choice. Using the German vehicle market as a research case, Paper I employs consumer choice theory and examines cost efficiency as one important utilitarian dimension (Al-Alawi & Bradley, 2013a; To et al., 2007).

For the owner of a vehicle, both purchase and operating costs are relevant for a comprehensive comparison of cost efficiency. The total cost of ownership (TCO) method calculates all costs accruing to the consumer during his or her ownership period and has been commonly applied in research (e.g. Lin et al., 2013; Thiel et al., 2010; Tseng et al., 2013). Existing TCO studies typically examine individual vehicle classes or use cases and mostly apply deterministic input parameters. A broader study across different market segments using probabilistic instead of deterministic parameters could improve our understanding of the consumer perspective in two ways. First, it would provide a more complete picture, showing the market segments the policies designed to support a market transition towards a new technology that are most likely to influence the cost efficiency for consumers. A lack of such a wide-ranging view can lead to forfeited opportunities for firms to develop radical innovations or missed policy targets, as past cases in the energy sector have shown (e.g. Arocena et al., 1999; Peters et al., 2012). Second, analyzing the probabilities and distributions of possible outcomes instead of calculating deterministic outcomes provides a better indication of whether policy measures can potentially affect the comparative cost efficiency of different technologies. For instance, uncertain TCO with overlapping outcome distributions among technologies indicate that policy measures will have the potential to influence the comparative TCO ranking of these technologies. In contrast, clearly determined TCO among technologies with distinct outcome distributions indicate that policy measures will have less potential to influence the comparative TCO ranking of these technologies.

In conclusion, paper I aims at providing a market-wide analysis of the cost efficiency of a new technology compared to the conventional technology with the following research question.
Such an analysis helps to understand how the intensity of policy support could be customized to specific segments in order to achieve higher effectiveness.

*How does the total cost of ownership of electric vehicles compare to that of conventional vehicles across the major vehicle classes and driving distance cases?*

### 2.2 Paper II: Firm knowledge search – understanding the effect of policies on firm knowledge search behavior

To assess the effect of policies on firms’ search behavior for knowledge, this dissertation draws on firm knowledge search literature. Firm knowledge search can be defined as a problem-solving effort to create new products (Ahuja & Katila, 2001). The literature suggests that product and process innovations, which are key determinants of a firm’s financial performance, require firms to engage in a search process in order to gain knowledge (Dahlander, O’Mahony, & Gann, 2014; Katila & Ahuja, 2002). To develop radical innovation, such knowledge often needs to be distant from the existing knowledge base of the firm (W. Mitchell & Singh, 1993).

Considering the effect of firm knowledge search on the performance and survival of a firm, scholars have researched the antecedents of firm knowledge search in more detail. In this, studies identified antecedents of firm search both within and outside the firm. From the firm-internal perspective, studies have found evidence for the effect of the organizational context on firm search. Here, the firm’s slack resources, breadth of knowledge base, external partnerships (e.g. via alliances), employee mobility, firm size, and financial performance have been found to be explanatory for the firm’s search strategy. From the perspective outside of the firm, research has focused on the effects of environmental conditions determined by the constellation of the supply-side agents and the characteristics of the core industry technology on firm search.

Despite many insights on how internal and external factors affect firm knowledge search, research has remained silent on how public policy as a formal institution can influence firms’ inclination to pursue different search strategies (Lavie, Stettner, & Tushman, 2010). The few existing studies contributing to this topic were conducted as case studies without quantitative tests of the proposed effects (e.g. Hoppmann et al., 2013; Nemet, 2009). Technological change literature proposes two ways by which public policy can influence firm search: technology-push or demand-pull (Dosi, 1982; Rosenberg, 1969, 1974). Thus, technology-push policies are designed to foster the advances in science and technology to increase the supply of technologies.
Demand-pull policies are designed to change the market conditions to increase the demand for technologies. Both type of policies are found to influence the scope and distance of firms’ knowledge search (Hoppmann et al., 2013; Nemet, 2009). Thereby, search scope describes “the degree of new knowledge that is explored” (Katila & Ahuja, 2002, p. 1184) when firms develop new technologies (Katila & Ahuja, 2002; Piezunka & Dahlander, 2015). By supporting new technologies, both technology-push and demand-pull policies are found to raise the degree of knowledge available in a technological field (Freeman & Perez, 1988; Jaffe et al., 2002; Mowery & Rosenberg, 1979; Salter & Martin, 2001). Search distance is defined as the degree to which knowledge outside the current technological domain is used (Rosenkopf & Nerkar, 2001). Research suggest that technology-push and demand-pull policies affect search distance differently. Technology-push policies are found to foster technological innovation outside the existing technological domains (Freeman, 1996; Freeman & Perez, 1988; Mowery & Rosenberg, 1979). In contrast, demand-pull policies are regarded as a selection mechanism that facilitate technological innovation within the existing technological domains (Freeman, 1996; Mowery & Rosenberg, 1979). However, recent research has started to question this view. For instance, researchers found evidences that demand-pull policies can increase the amount of financial resources that can be used to finance distant research (Hall & Lerner, 2009; Hoppmann et al., 2013).

Resolving these contradictory findings and putting public policies in relation to detailed firm search dimensions is important for my objective to understand how policy makers can facilitate the development of innovations. Hence, paper II assesses the effect of demand-pull and technology-push regulations on firm search scope and distance. In addition to these two firm search dimensions, this paper also considers the moderating effect of firms’ initial knowledge breadth, which “refers to the extent to which the firm’s knowledge repository contains distinct and multiple domains” (Zhou & Li, 2012, p. 1091). Knowledge breadth has been found to be explanatory for the firm’s absorptive capability to process and leverage technological opportunities such as policy induced support (Cohen & Levinthal, 1989; Moorthy & Polley, 2010; Zahra & George, 2002; Zhou & Li, 2012).

In conclusion, Paper II aims at understanding the effect of policies on firm knowledge search with the following research question. Such an understanding helps me to derive policy implications indicating how policy makers can support the development of new technologies by firms.
What is the impact of demand-pull and technology-push policies on firm knowledge search?

2.3 Paper III: Institutional entrepreneurship – understanding the firm-specific benefits of developing and introducing non-proprietary technologies

To assess how firms develop new technologies, I build on the theoretical perspective of institutional entrepreneurship. This stream of literature defines an institutional entrepreneur as a self-interested agent who mobilizes resources to change his or her institutional environment (Anderson & Hill, 2004; DiMaggio, 1988; Eisenstadt, 1980). One commonly examined process of institutional entrepreneurship is the legitimation of new technologies (e.g. Garud, Jain, & Kumaraswamy, 2002; Hippel & von Krogh, 2003; Tracey, Phillips & Jarvey, 2011). Existing literature has demonstrated how such legitimation, driven by an individual firm, can create or change the institutional arrangements of an entire organizational field (e.g. Greenwood & Suddaby, 2006; Hargrave & Van De Ven, 2006; Munir & Phillips, 2005). Less is known about the consequences of such legitimation for the individual firm that promotes a new technology. Existing research has focused on the individual sponsoring of proprietary technologies where the technology per se (e.g. Java-technology for the firm Sun Microsystems) grants competitive benefits to the proprietor (Garud et al., 2002). However, we also empirically observe many cases in which firms engage in institutional entrepreneurship for non-proprietary technologies such as EV or nanotechnology. Once the legitimacy of such non-proprietary technology is established, it is available to all seeking rents in this technological field and thus is a form of collective good (Barnett, 1990; Hall & Martin, 2005; Spar & La Mure, 2003). Since competitors can benefit from the established legitimacy without investing in the process of legitimation (Hargrave & Van De Ven, 2006; Olson, 1965; Pacheco et al., 2010; Panchanathan & Boyd, 2004), it is important to understand what benefits not available to free riders a firm can gain from institutional entrepreneurship for a non-proprietary technology.

One suggested approach to scrutinize these benefits is “distinguishing between the individual benefits that institutional entrepreneurs accrue from their initiatives and the collective benefits that the organizational field enjoys from such actions” to show whether “institutional entrepreneurship action offers an advantage to institutional entrepreneurs over their competitors” (Pacheco et al., 2010, p. 996). This suggestion resonates with recent studies on open source software developers. The results of these studies indicate that the participation in the development of collective goods can grant access to intangible benefits not available to non-
participants such as learning, reputation, and reciprocity (Hippel & von Krogh, 2003; Horbach, 2008; Roberts, Hann, & Slaughter, 2006; Von Krogh, Haefliger, Spaeth, & Wallin, 2012; Wasko & Faraj, 2005). So far, these studies have exclusively focused on individual people such as software developers and the antecedents and effects of their activities.

Existing research leaves two questions open. First, what competitive benefits can a firm (rather than an individual) gain in the process of institutional entrepreneurship for non-proprietary technologies? Second, what are the mechanisms which explain how these benefits are gained inside the firm? The answers to these questions would reveal firm-specific advantages of developing new technologies that are non-proprietary, and provide suggestions on how to realize these advantages. Paper III aims at addressing this current research gap by assessing how firm-specific benefits emerge within the process of institutional entrepreneurship within one of the largest chemical firms in the world. Thus, paper III contributes to my overall research objective of understanding how firms can facilitate the development and introduction of environmental innovations. The specific research question of this paper reads as follows:

*How does a firm gain firm-specific benefits from acting as an institutional entrepreneur that champions a non-proprietary technology?*

2.4 Paper IV: Stakeholder theory – understanding the process of secondary stakeholder management during the development and launch of innovations

To examine how firms launch innovations with special consideration of stakeholders, I draw on stakeholder theory. As introduced by Freeman (1984), stakeholder theory suggests that research on the relationships between a business and the groups and individuals who can affect or are affected by it can advance our understanding of value creation, ethics, and managerial decision making (Parmar et al., 2010). Empirically, researchers found evidence that the appropriate involvement of stakeholders can enhance firm performance (Berman, Wicks, Kotha, & Jones, 1999; Hillman & Keim, 2001; Preston & O’bannon, 1997), whereas neglecting stakeholders can result in negative consequences for the firm and its businesses (Baron & Hall, 2003; Frooman, 1997; Whysall, 2000). Hence, the term strategic stakeholder management was introduced by Berman et al. (1999) to describe the type of stakeholder management motivated by improving financial performance of the firm.

Although strategic stakeholder management is carried out by the firm, literature suggests that some stakeholder issues require collaborative efforts among many firms (Steadman, Zimmerer,
Specifically, complex stakeholder issues with widespread effects on the industry often require cooperative actions among diverse industry players – even among previous adversaries (Buysse & Verbeke, 2003; Steadman et al., 1995). Despite the recognized need of individual and cooperative strategic stakeholder management, the existing literature on the process of stakeholder management almost exclusively focuses on firm-individual practices along four core themes. The first stream of literature further defines the concept of stakeholder management by studying its various sub-constructs such as stakeholder identification, interaction, and integration of their demands (Plaza-Úbeda, Burgos-Jiménez, & Carmona-Moreno, 2010; Sharma & Vredenburg, 1998). A second stream of research focuses on the process of stakeholder identification and prioritization (Ackermann & Eden, 2011; R. K. Mitchell, Agle, & Wood, 1997; Vos & Achterkamp, 2006). A third stream of research examines different response strategies such as fighting, waiting, or withdrawing, depending on the stakeholder issue (Clarkson, 1995; Lawrence, 2010). The last stream of research applies the concept of stakeholder management to specific empirical contexts such as the development and launch of innovations (Driessen & Hillebrand, 2013; Driessen, Kok, & Hillebrand, 2013; Yip, Phaal, & Probert, 2013). Thus far, studies in this area confirm positive effects of stakeholder management techniques such as “stakeholder issue identification techniques, (2) coordination mechanisms, and (3) prioritization principles” (Driessen & Hillebrand, 2013, p. 375). Hence, although the literature provides general concepts and definitions of stakeholder management (Ackermann & Eden, 2011; A. T. Lawrence, 2010), the detailed mechanisms of stakeholder management which should reveal “who did what when […] over time” (Langley, 1999, p. 692), remain relatively unstudied.

Paper IV aims at scrutinizing these detailed mechanisms with the practical question of how firms manage secondary stakeholders in order to launch innovations. Since secondary stakeholders can significantly influence the success of innovations (Driessen & Hillebrand, 2013), the answer to this question contributes to the overall objective of my research. Based on the literature review, my co-authors and I identified three main literature gaps. First, since research has defined many elements of strategic stakeholder management, studies should proceed to a more detailed level to assess what practices underlie these elements. Second, it should be further clarified when each of these practices is relevant along time. Third, since some complex stakeholder issues cannot be addressed by an individual firm, showing which of the
practices are conducted by one firm individually and which in cooperation with other firms could further advance our understanding of who should conduct the respective practices.

In conclusion, existing literature does not offer detailed descriptions of steps firms can take to manage secondary stakeholders in order to avoid stakeholder issues and to enable a problem-free market introduction of new technologies. As this dissertation aims at understanding how firms can facilitate the introduction of new technologies, such insights contribute to my overall research objective. Hence, paper IV asks:

How can firms conduct strategic management of secondary stakeholders along the innovation process of a radical technological innovation?

3 Methods and Data

The papers underlying this dissertation scrutinize different levels of perspectives and explore diverse research questions. To use the best-fitting methodology for each paper, I employ both quantitative and qualitative research methods leveraging their complementary strengths. For this, quantitative methods are used to assess the policy-level perspective (in papers I and II), whereas qualitative methods are used to assess the firm-level perspective (in papers II and III).

This dissertation also assesses different empirical cases because one case alone does not have the crucial events or the broad data basis necessary for the assessment of all the relationships of interest. For instance, the PV case is appropriate to assess the relationship between policy and firms, but does not provide the opportunity to assess a high variance of consumer segments. On the other hand, the EV case is appropriate to assess many consumer cases, but does not experience any significant deployment policies. In total, five different cases were scrutinized by the four papers included in this dissertation. The electric vehicle case was used to assess the differences in cost efficiency of a new technology for different market segments (cf. paper I). The PV case was used to assess the effects of policies on firm search behavior (cf. paper II). To assess the benefits of introducing non-proprietary technologies (cf. paper III) and the process of secondary stakeholder management during the development and launch of innovations (cf. paper IV), the following four different cases were examined in order to triangulate the patterns across cases: electric vehicles, nanotechnology, biodegradable plastics, and GMO. Table 2 presents an overview of the methods and cases used for the respective paper in order to fulfill the research objective (cf. section 2). More details on the methods per paper are outlined in the following subsections.
Table 2. Overview of methods and cases for each paper

<table>
<thead>
<tr>
<th>Papers</th>
<th>Research objective</th>
<th>Method used</th>
<th>Empirical case</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>To assess the differences in cost efficiency of a policy-supported technology across market segments</td>
<td>Probabilistic techno-economic modeling (cf. section 3.1)</td>
<td>German electric vehicle market</td>
</tr>
<tr>
<td>II</td>
<td>To assess the effects of policies on firms’ knowledge search behavior to develop new technologies</td>
<td>Panel data regression (cf. section 3.2)</td>
<td>Global PV market</td>
</tr>
<tr>
<td>III</td>
<td>To assess the firm-internal mechanisms of gaining competitive benefits from conducting institutional entrepreneurship for non-proprietary technologies</td>
<td>Analytic induction through case studies (cf. section 3.3)</td>
<td>Development and market introduction of electric vehicles, nanotechnology, biodegradable plastics, and GMO product</td>
</tr>
<tr>
<td>IV</td>
<td>To assess detailed firm practices of managing secondary stakeholders during development and introduction of new technologies</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1 Paper I – Probabilistic techno-economic modeling

Paper I uses technology-economic modeling in order to assess the differences in cost efficiency of a new technology for different market segments. Since the EV case is employed as the research context, this study calculated the comparative cost efficiency of EV compared to conventional vehicles. For this, my co-authors and I used the discounted TCO per kilometer (TCO/km) as the relevant indicator to compare different vehicle types including internal combustion engine (ICEV), hybrid electric (HEV), plug-in hybrid (PHEV), and battery electric vehicles (BEV). To calculate the TCO/km, we used technical (e.g. battery depth of charge) and economic (e.g. interest rates, fuel prices) input parameters. The following formula describes the basic approach of the TCO calculation:
Due to the wide range of possible values of important input parameters such as fuel, electricity, and battery cost development, probabilistic instead of deterministic analyses (as conducted by most existing studies) are more appropriate and can yield better policy insights. To conduct probabilistic analyses, this calculation applies probabilistic input parameters, which we drew from multiple sources such as Statista, the International Council of Clean Technology, VDA, the EU Commission, New European Driving Cycle, and the German Federal Motor Transport Authority. Subsequently, we used the statistical distribution among these data to calculate the distribution of possible TCO outcomes using Monte Carlo simulations. The uncertainty of input parameters was taken into account for the initial values in 2014 as well as the projection of these values until 2025.

The model incorporates four types of distributions. For the calculation of the results in 2014, we used the PEARSON and Beta distribution. The PEARSON distribution was applied to parameters for which we had empirical data. The Beta distribution was used if the data cannot have negative values (e.g. costs of vehicle parts). For the projection of the results to the years 2020 and 2025, we used PERT and normal distribution. For this, PERT distribution was applied for the yearly change of those parameters for which we received validated assumptions by experts. The Normal distribution was used for the annual development of the yearly improvement in fuel economy and electric energy usage, which are expected to be distributed normally (Plötz, Gnann, Kühn, & Wietschel, 2013). In addition, the Monte Carlo simulations account for possible correlations among input parameters. For instance, we correlated fuel and electricity prices based on historical data. Also, the ICEV purchase price and the glider price projections in the future are correlated. Lastly, we tested our outcomes in multiple rounds of

$$ TCO / km = \frac{(IPC - RV \times PVF) \times CRF + \frac{1}{N} \sum_{n=1}^{N} AOC \times (1+i)^n}{AKT} $$

TCO/km: Total cost of ownership per kilometer [EUR/km]  
IPC: Initial purchase cost of vehicle [EUR]  
RV: Resale value [EUR]  
PVF: Present value factor  
CRF: Capital recovery factor = \frac{i(1+i)^N}{(1+i)^N-1}  
AOC: Annual operating cost [EUR]  
AKT: Annual kilometres travelled [km]  
N: Vehicle holding period of first owner [years]
simulations (with 10,000 iterations per simulation). All the simulations yield very similar results (with a maximum deviation of 3% among the comparable outcomes).

3.2 Paper II – Panel data regression

Negative binominal and fractional logit regression models were used for Paper II to scrutinize the effect of demand-pull and technology-push policies on search scope and search distance, respectively. In the following, I briefly introduce the data, variables, and model considerations.

We used three forms of data. To approximate search scope and distance, we gathered global patent data for solar PV technology between 1988 and 2012 and analyzed the citation patterns among them. This approach is in line with leading studies in this field (e.g. Katila & Ahuja, 2002; Kim, Arthurs, Sahaym, & Cullen, 2013; Rosenkopf & Nerkar, 2001). To extract the relevant global patent data from the “Thomson Innovation” database, we used a search string, which screens the international patent classification code (IPC) as well as the titles and abstracts of each patent. As a result, 96771 patents were extracted and further processed. For instance, we removed the examiner citations from each patent since these citations are not created by firms (Alcácer and Gittelman, 2006). To approximate demand-pull and technology-push policies, we used data from the International Energy Agency and European Photovoltaic Association. To gather firm-level data, we drew on sources such as Compustat, Thomson Reuters EIKON, and Zephyr. The data from these different sources were compiled together to a firm database. All together, these different forms of data were aggregated to a set of longitudinal panel data for the years from 1988 to 2012.

Regarding the independent variables, technology-push policies were approximated by the amount of R&D funding for PV technology (Peters et al., 2012). Demand-pull policies were approximated by the yearly market subsidies for PV using the levelized cost of electricity (LCOE). This method compares the cost of solar electricity for a specific year in a specific country with the wholesale electricity price and assumes that the difference between the more expensive solar electricity and wholesale prices needs to be subsidized by demand-pull funding to make investments in PV profitable. Following this method, the annual cost difference of solar PV was calculated for each of the countries and years in our sample and then consolidated to estimate the annual, global demand-pull funding (Branker et al., 2011). This global measure is important because previous studies indicate that country-specific demand-pull policies have a global effect on knowledge generation (Peters et al., 2012). In addition to policies, we included
the degree of knowledge breadth as a moderating variable. It was estimated by the count of different technological PV domains a firm was technically or commercially involved with within the PV industry.

Regarding the dependent variables, we calculated search scope as the number of patent citations in a firm’s patents for a specific year (cf. Katila and Ahuja, 2002). Search distance was measured as the Euclidean distance of the technology categories between the consisting portfolio of a firm’s patent and the citations the firm has within its patents in a specific year. The allocation of technology categories for patents and cited patents was conducted through a self-developed algorithm which searches for key words in the title and abstracts of all patents within the database.

Based on literature suggestions, we included firm size, financial performance, number of R&D alliances, number of mergers and acquisitions (M&A), employee mobility, slack resources, R&D intensity, and environmental uncertainty as control variables. In addition, to control for unobserved effects, we included year and firm dummies as fixed effects in our analyses.

We used two types of models to assess our hypotheses. For the analysis of count data, which applies to the assessment of search scope, we used a negative binomial regression model. The negative binomial regression is more appropriate than the Poisson model since a log-likelihood test of our independent variables showed that over-dispersion was problematic (Cameron & Trivedi, 2010). For the analysis of search distance, which had values between 0 and 1, we used fractional logit regression. For both types of regressions, we tested several models. First, we used a base model only including the control variables. For the next models, we subsequently added the main effects (demand-pull and technology-push policies). For the most specified model, we included the interaction effects of the moderating variable “knowledge breadth” with each of the independent variables.

To check the robustness of our models, we also analyzed the change in installed PV capacity per year and country. Such an approximation based on market growth has been used in many recent studies assessing the effect of demand-pull policies across several industries (Henderson and Cool, 2003; Klaassen et al., 2005; Peters et al., 2012). It is based on the assumption that the market development is mainly policy-induced because the technology itself is not yet competitive. This assumption is reasonable for the PV industry as the levelized cost of
electricity (which is a standard normalized comparison indicator of cost efficiency of electricity) of PV capacity has been considerably above wholesale electricity (Branker et al., 2011).

3.3 Paper III and IV – Analytic induction through case studies

To research the mechanisms of institutional entrepreneurship and stakeholder management within the firm in depth, papers III and IV use qualitative case study designs (Yin, 2009). A case study design is especially appropriate for developing theory through the understanding of particular events or situations in depth (Eisenhardt, 1989; Siggelkow, 2007), which is the goal of papers III and IV (cf. section 3.3 and 3.4). In order to focus on the core event and to control for other context factors (e.g. characteristics of a firm’s structural setting for the legitimation process), my co-authors and I examined multiple cases nested within one firm (Eisenhardt, 1989). This allowed us to repeatedly enter a similar research environment for iterative data collection from multiple sources, such as interviews, workshops, and observations (Eisenhardt & Graebner, 2007; Yin, 2009). Since papers III and IV had the same unit of analysis, which is the development and launch process of an innovation, we gathered data for both papers simultaneously. The research was conducted at one of the largest chemical firms in the world, with many prominently and publicly discussed innovation cases. Employing theoretical sampling, we selected cases which fit the respective purpose of the study. For instance, we selected innovation cases exclusively dealing with non-proprietary technologies (to fit paper III) and that required extensive secondary stakeholder management (to fit paper IV).

Following the analytic induction approach, we conducted iterations between data and theory. In addition to the required analytic iterations, we also designed our data collection process in an iterative way. Our approach included two rounds of interviews, multiple site visits, joint workshops for results clarification, and application of insights to pilot cases. In summary, the whole data collection process consisted of the following steps.

As a first step, my co-authors and I conducted comprehensive desk research to understand the selected innovation cases. As a second step, we conducted semi-structured interviews with experts and managers within the sample firm representing the different business and functional areas relevant to our cases. Subsequently, we undertook a joint discussion workshop with firm representatives from the respective business and functional areas to discuss and validate the emerging constructs and propositions we deduced from the first interview round. In a fourth step, the research team conducted another round of interviews with new interviewees. All
interviews were recorded and transcribed. After this second round, we refined our results, which were again discussed in a fifth step in a joint meeting. The data collection process lasted about eight months.

We followed the approach suggested by Miles and Huberman (1994) for the data analysis. The approach involves the five major steps of data transcription, coding, themes and trend identification, shaping propositions, and delineating the deep structure. We developed initial high-level codes based on existing theories. The coding process itself was done by three researchers independently using the coding software MAXQDA®. Minor frictions from the evaluation of the inter-coder agreement were discussed and resolved in joint meetings and sometimes resulted in further refinement of our codes. As a next step, all researchers discussed and agreed on second-order codes (Locke, 2001). These second-order codes were then used to develop theoretical constructs, which we triangulated across cases and sources (Eisenhardt, 1989). The empirical observations related to the field level were triangulated through press articles and other archival data. After the development of initial theoretical constructs based on the empirical observations, another management workshop was conducted in which we discussed our emerging theoretical framework. We closed our research when statements from interviewees and workshop participants and further triangulation of the data did not result in further changes of the theoretical constructs and their relationships.

4 Summary of results

This section provides a summary of the most important results of the four individual papers. The contribution of these results to my overall research question and the implications for policy makers, managers, and academic scholars are discussed in section 5.

4.1 Paper I - Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments

Paper I assesses the cost efficiency of electric vehicles compared to conventional vehicles in order to understand the differences in cost efficiency of a new technology for different market segments. We refer to each possible combination of the powertrain technologies and vehicle classes and use cases as one TCO case. Figure 3 shows the mean TCO/km results for the years 2014, 2020, and 2025 for each of the TCO cases. In general, the model projects that the cost efficiency of the four powertrain technologies will be much closer to a single common value in
2025 than in 2014. However, the results vary significantly across the TCO cases. In the short distance cases, the mean cost efficiency of PHEV and BEV are likely to remain higher than the cost efficiency of ICEV and HEV. However, the cost gap converges strongly until 2025. In contrast, in the long distance cases, BEV can become the cheapest technology in the small vehicle class in 2020. In the medium and large classes, HEV is likely to be the technology with the lowest cost efficiency followed by BEV. Interestingly, PHEV has higher mean cost efficiency than BEV in each vehicle class of the long distance cases.

Figure 4 shows the distribution of all TCO/km outcomes for each TCO case. Such a distribution of cost efficiency is the consequence of the uncertainty of the input parameters (cf. section 3.1). In the short distance cases, ICEV has the lowest mean and minimum value. In the medium distance cases, the results are more overlapping than in the cases of the other distances. In the A/B class, HEV and PHEV have almost the same results regarding both the mean value and the distribution of outcomes. In the C/D and J class, HEV has the lowest mean TCO/km. However, its results are highly overlapping with the results of ICEV. In the long distance cases, the A/B class is likely to have BEV as the technology with the lowest TCO/km indicated by both the mean TCO/km and the distribution patterns. For the other classes, the results of at least two technologies are highly overlapping.

In conclusion, the results show that the comparative cost efficiency among the vehicle technologies highly depends on the vehicle class and annual driving distance of the consumer. In addition, the future comparative cost efficiency is still uncertain and might hence be influenced by policy measures. Three main policy implications can be derived from the results. First, customers should be educated about the TCO fitting to their respective vehicle preference and driving distance. Otherwise, customers might intuitively consider only the capital cost, which is higher for EV than for conventional vehicles in all cases (Offer, Contestabile, Howey, Clague, & Brandon, 2011). Cost labels signaling the cost efficiency of vehicles per driving distance category and a recognized online TCO calculation platform are two possible measures of customer education. Also, the support of a market shift toward smaller vehicles per se would promote EV because they are more cost-efficient in the smaller vehicle classes than the larger ones. Second, the charging infrastructure between cities needs to be developed to obviate the seeming contradiction between the positive effects on the comparative cost efficiency of EV of increased driving distance and the limited driving range of EV compared to conventional cars. For this, the currently regional infrastructure initiatives of communities could be organized into
supraregional initiatives to increase the charging network density and introduce innovative ways of energy provision. Third, increased public R&D spending and more international funding programs could support a decrease in battery price, which would have a high impact on the TCO.

Figure 3. TCO/km projection until 2025.
**Figure 4.** Distribution of TCO results in 2025.

### 4.2 Paper II – The effect of demand-pull and technology-push policies on firm knowledge search – the case of global solar photovoltaic industry

Paper II aims at testing the effect of demand-pull and technology-push policies on firm knowledge search scope and distance. Table 3 summarizes the hypotheses and findings of our regression analyses.

In summary, our results provide several important insights for the effect of policy support on firm knowledge search. In contrast to many previous studies indicating that demand-pull and technology-push policies may increase knowledge generation, our results provide quantitative evidence that these policies may lead to narrower search scope by firms and thus to less knowledge generation. Thereby, a broader initial knowledge base may reduce this effect for technology-push policies. These findings indicate that policy incentives might support firms to find a solution more quickly, narrow firms’ attention due to information overload, and raise the opportunity cost of search (Piezunka & Dahlander, 2015). A broader initial knowledge base might facilitate firms to absorb the high amount of knowledge generated by technology-push...
policies more easily and hence reduces the negative effects of technology-push policies on search scope. As a second main finding, our results suggest that technology-push policies may lead to distant search across technological domains, while demand-pull policies may reduce the search distance. This finding indicate that technology-push policies may have variety-enhancing effects fostering development of new technologies relatively independent from the market. In contrast, demand-pull policies may increase the pressure on firms to select new technologies along established trajectories in order to immediately leverage the induced market incentives.

Table 3. Summary of hypotheses tests

<table>
<thead>
<tr>
<th>Hypotheses</th>
<th>Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a  The larger the funding for technology-push policies, the narrower a firm’s search scope.</td>
<td>Supported</td>
</tr>
<tr>
<td>1b  The larger the funding for demand-pull policies, the narrower a firm’s search scope.</td>
<td>Supported</td>
</tr>
<tr>
<td>2a  The larger the funding for technology-push policies, the larger a firm’s search distance.</td>
<td>Supported</td>
</tr>
<tr>
<td>2b  The larger the funding for demand-pull policies, the smaller a firm’s search distance.</td>
<td>Supported</td>
</tr>
<tr>
<td>3a  The larger the breadth of the firm’s knowledge base, the less technology-push reduce a firm’s search scope.</td>
<td>Supported</td>
</tr>
<tr>
<td>3b  The larger the breadth of the firm’s knowledge base, the less demand-pull policies reduce a firm’s search scope.</td>
<td>Not supported</td>
</tr>
</tbody>
</table>

4.3 Paper III - From institutional entrepreneurship to competitive advantage: How firm-specific benefits can emerge from legitimation of non-proprietary technologies

After examination of the effect of regulations on firm search behavior in paper II, paper III looks at the mechanisms inside the firm in order to examine how firm-specific benefits might result from institutional entrepreneurship for non-proprietary technologies. Figure 5 presents the theoretical framework summarizing the main insights of the study. The temporal scope ranges from the start of the innovation development, which is called the fuzzy front end phase,
until the market launch of the resulting end product. Within this temporal scope, my co-authors and I derived three core processes from the case observations.

First, institutional entrepreneurship was mainly characterized by cooperation with other stakeholders and political tactics to create and maintain legitimacy for the new technology. To conduct legitimation, our sample firm actively involved multiple stakeholders (e.g. industry associations, scientific institutions, media, other firms) from the early development phase on. This early involvement of stakeholders helped to generate basic knowledge, set common standards, and shape the regulatory environment for the new technology. In parallel, our sample firm communicated the advantages of the new technology through several channels (e.g. websites, public forums, press releases) to convince the broader public. Later, when first pilot products were developed, public and regulatory attention arose and issues evolved in every case. To counteract these issues, our sample firm collaborated with other firms and stakeholders partly drawing on platforms and relationships built from the earlier phases. These countermeasures can be described as activities to maintain the legitimacy of the new technology.

Second, we observed how the institutional entrepreneurship activities led to the development of three types of firm-specific resources. Networks with stakeholders such as regulatory authorities and scientific institutions were developed in the process of joint development of the basic knowledge required for the new technology as well as the industry standards. Knowledge of stakeholder demands evolved naturally during the stakeholder interactions such as exchange of test results, stakeholder forums, and security discussions, within the legitimation process. These interactions and the effort of the firm to facilitate a non-proprietary technology led to a positive reputation with the stakeholders.

Lastly, we observed how these resources contributed to differentiation advantage for the firm-specific products as well as institutional entrepreneurship for the general technology. Regarding differentiation advantage, our results show that shorter time to market can be achieved through networks built in the earlier phases. For instance, the relationship with regulatory authorities led to a more efficient collaboration resulting in a faster admission process. In addition, the knowledge of stakeholder (not only customer) demand can improve the development process in two ways. First, the product specifics can be adjusted more to fit the needs of stakeholders other than the direct customers to prevent later problems or improve the end product. Second, the collaboration along the value chain can become more efficient if the focal firm knows the
In one of our cases, we evidenced how the chemists of the focal firm learned to work more efficiently with engineers down the value chain, which in turn leads to more efficient product development process. As a last differentiating factor, the reputation of the firm-specific products with the customers can be improved by the endorsements and support of other stakeholders. Such support stem from the good reputation with the other stakeholder built in the earlier processes. Once the firm-specific resources are created, CHEMCO also mobilized these to support the institutional entrepreneurship for the underlying technology. Such recursive facilitation between institutional entrepreneurship on the field level and resource creation on the firm level were observed in all four cases. Together, these findings confirm that institutional entrepreneurship for a non-proprietary technology can still contribute to competitive benefits and show the mechanisms involved in the emergence of these benefits.

Figure 5. Theoretical framework of paper III

4.4 Paper IV - The process of strategic management of secondary stakeholders:
Evidence from four innovation cases

After the assessment of the motivations and mechanisms of firms engaging in institutional entrepreneurship for non-proprietary technologies in paper III, paper IV assesses an important management process in order to successfully introduce an innovation – the process of strategic management of secondary stakeholders. As pointed out in section 2.4, existing studies have

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delineated the elements of strategic stakeholder management, but still neglect to show the detailed practices along time and whether the firm conducted the respective practices alone or in cooperation with other firms. Figure 6, which is the overall resulting framework of this paper, presents detailed strategic stakeholder management practices along the innovation process and indicates whether these practices were rather done by our focal firm alone or in cooperation with other firms. In summary, we evidenced the following nine practice categories in chronological order of first occurrence: (1) develop basic knowledge, (2) exchange and refine knowledge, (3) define industry standard, (4) strengthen public acceptance, (5) participate in regulatory discussions, (6) support new product development, (7) support product launch, (8) maintain normative legitimacy, and (9) maintain regulatory legitimacy. The observed practices and temporal occurrence are mostly consistent across all cases. Only a few practices were not observed in some cases due to the lack of necessity. In the electric vehicle case for instance, there was no need for maintenance of regulatory legitimacy because the regulatory authorities themselves were very supportive of the new technology.

Regarding the question of who conducted the respective practices, we found evidence for two main patterns which were observed in the successful cases, but not observed in the less successful ones. First, from the start to the end of the innovation process, we observed a shift from cooperative practices with other firms to firm-individual practices. Second, in the late phase of the innovation process, we observed how cooperative practices led to more successful case outcome than firm-individual practices when it came to maintaining the legitimacy of the new technology. This is partly due to the complexity of legitimacy issues, which often involve multiple stakeholders and hence require the joint effort of many firms. Some advantages of cooperative practices mentioned by the interviewees were credibility (as an industry compared to one firm), resource sharing, and reach of communication. Hence, despite the fact that the late phase of the innovation process is mainly characterized by firm-individual practices to launch their own products, we also observed a return to cooperative practices when the legitimacy of the technology is threatened.
5 Conclusion

To answer to the questions of how policy makers and firms can facilitate the launch of new technologies with consideration of the perspectives of consumers and stakeholders, this dissertation yields insights for policy makers and firms. Table 4 summarizes the most important insight contributing to the answer of my overall research question. These and other insights are discussed in more detail in the following sections. In section 5.1, I present suggestions on how policy makers can optimize policy initiatives based on the variance of the cost efficiency of a new technology across different consumer segments and the effect of policies on firm knowledge search. Subsequently, I discuss how firms can facilitate the successful launch of their innovations in section 5.2. Finally, in section 5.3, I present the theoretical contributions to the literature streams I drew on in the respective papers.

Table 4. Answers to the overall research question from each paper

<table>
<thead>
<tr>
<th>Overall research question</th>
<th>Target audience</th>
<th>Papers</th>
<th>Main insight contributing to the answer of the overall research question</th>
</tr>
</thead>
<tbody>
<tr>
<td>How can policy makers and firms facilitate the development and introduction of new technologies with consideration of multiple stakeholder perspectives?</td>
<td>Policy makers</td>
<td>I</td>
<td>The cost efficiency of a new technology compared to the conventional technology might be significantly different across market segments. Hence, policies designed more specifically for different market segments might be more effective to promote a new technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td></td>
</tr>
</tbody>
</table>
Innovation policies may lead to lower search scope by firms and therefore indicate faster solution finding, focused attention, and higher opportunity cost of alternative search. Hence, policies have significant effect on firm behavior and might increase the speed of developing and introducing a certain technology. However, the right mix of technology-push and demand-pull policy is required to keep a certain degree of technology exploration.

Firms III Firms engaged in institutional entrepreneurship for non-proprietary technologies do not only create legitimacy for the overall technology, but can also gain competitive benefits for their own end product. Hence, mobilizing resources to create legitimacy for a new technology might be a reputable way for a firm to gain competitive advantage.

IV Proactive development of broad collaboration platforms with other firms (and even competitors) in the early phase of innovation development can create the opportunity for a later return from firm-individual practices to cooperative practices. These cooperative practices are required to solve complex stakeholder issues.

5.1 Theoretical contributions

In terms of the main theories employed in this dissertation (cf. section 2), this dissertation yield four main theoretical contributions. First, it advances innovation theory by showing that the cost efficiency of a new technology varies significantly across market segments. Hence, segment-specific policies might be more effective in fostering the development and market introduction of new technologies than generic policies for the whole market (cf. paper I).

Second, this dissertation advances our understanding of the effect of demand-pull and technology-push policies on firm knowledge search and hence contribute to the literature on organization search and innovation policies (cf. paper II). Third, my results contribute to a more detailed understanding of how institutional entrepreneurship for non-proprietary technologies, which is often applicable to new technologies that avoid or reduce environmental damage, can create competitive benefits for the entrepreneurial firm (cf. paper III). Fourth, this dissertation opens the corporate “black box” and provides insights on how strategic stakeholder management can be conducted during the phases of the innovation process (cf. paper IV). This subsection discusses each of these contributions.

Thus far, innovation studies have had a rather high-level focus on the antecedents and effects of demand-pull and technology-push measures (Horbach, 2008; Nemet, 2009). However, these
studies have yielded mixed results concerning the reactions of the firms and the market to different policy measures. This dissertation helps to clarify why the results are so different. First, the breadth of the firm’s knowledge might significantly moderate the effect of public policies. Accordingly, firms with a broader knowledge base are observed to keep the search scope higher than firms with a narrow knowledge base under the conditions of demand-pull policies. Hence, the same public policy might trigger different reaction of firms dependent on their initial knowledge base. Second, due to the high variance of key comparative performance indicators such as cost efficiency across the market, new technologies might not diffuse consistently across market segments. In our EV case for instance, the comparative cost efficiency among technologies highly depends on the annual driving distance and vehicle class. In the short distance cases, conventional vehicles are very likely to stay the most cost-efficient technology until 2025. In the long distance ones, EV can be more cost-efficient than ICEV in 2025. In case the consumer has a long annual driving distance and possesses a small vehicle, EV can be more cost-efficient than conventional vehicles by as early as 2020. Hence, innovation theory could take the firm-specific and market-specific variances into account in order to derive more accurate implications for policy measures. As an example, studies can analyze the effect of demand-pull and technology-push measures on market segments within a national market instead of the national market as a whole. The resulting insights can advance our understanding of the difference of policy effects on different market segments. Such a quantitative, market-specific assessment of the effects of innovation policies on the market success of new technologies is still lacking.

From the observed effect of policies on firm knowledge search (cf. paper II), some theoretical implications for the organization search literature and literature on innovation policies can be derived. For the organization search literature, our research provides three main contributions. First, it shows that firm search is significantly affected by policy support as a formal institution. Therefore, organizational members might not have as much agency in choosing the search behavior of the firm as the current strategy literature suggests (Garriga et al., 2013; Laursen, 2012). Instead, in line with traditional change literature, we argue that certain search behavior is conditioned by the environmental context (Piezunka & Dahlander, 2015; Sidhu et al., 2007). Second, the results provide evidence that demand-pull and technology-push policies reduce search scope. This effect indicates that innovation policies facilitate knowledge creation and hence may foster firms to find solutions faster, have more narrow focus in order to cope with
the information overload, and react to the increased opportunity costs for alternative search. Hence, our findings extend previous literature on behavioral theory of the firm (Cyert & March, 1963). Third, our results indicate that firms with broader knowledge base tend to keep their search scope higher under the conditions of technology-push policies than a firm with less broad knowledge base. This indication is in line with the theoretical notion of absorptive capacity, which proposes that firms with broader knowledge base can have more diverse sources and might possess more diverse capabilities to leverage technological opportunities (Cohen and Levinthal, 1990; Zahra and George, 2002; Zhou and Li, 2012). For the innovation policies literature, paper II provides empirical test results that support the predominant literature proposition that technology-push policies serve as a variety creating mechanism that has a positive effect on search distance. On the other hand, demand-pull policies serve as a selection mechanism that has a negative effect on search distance (Freeman, 1996; Mowery & Rosenberg, 1979). To our knowledge, our study is among the first to test the influence of technology-push and demand-pull policies on search distance quantitatively.

For the literature on institutional entrepreneurship, the findings of this dissertation advance our understanding of how the institutional entrepreneur can gain advantage over competitors in three ways. First, this study improves our understanding of how institutional entrepreneurship is connected to competitive benefits on the firm level. Our results indicate that legitimation practices on the field level can contribute to creation of firm-specific resources and subsequently to competitive differentiation. Thus far, institutional entrepreneurship literature has produced rich insights in how field-level consequences result from the efforts of firms (e.g. Greenwood & Suddaby, 2006; Hoffman, 1999; Maguire, Hardy, & Lawrence, 2004). In our cases, we evidenced how institutional entrepreneurship practices such as involvement of multiple stakeholders to develop the basic knowledge, setting the industry standards, and shaping the regulatory environment led to field- and firm-level consequences. On the field level, the practices contributed to the legitimation of new, non-proprietary technologies. On the firm level, institutional entrepreneurship contributed to competitive benefits for the firm-specific end products based on the new technology. Garud et al. (2002) already claimed such competitive gains on the firm level by showing how Java conducted institutional entrepreneurship to gain the competitive benefits of the new technology per se. Our findings extend the notion of competitive advantage from the technology per se (as the technologies in our cases were non-proprietary) to advantage from the resulting firm-level resources. Second,
this study indicates a recursive relationship between institutional entrepreneurship and creation of firm-specific resources. Although studies on institutional work have proposed the reciprocal effects of agency and structure (Barley & Tolbert, 1997; Battilana, Leca, & Boxenbaum, 2009a; DiMaggio, 1988; Giddens, 1984; Pursey, Heugens & Lander, 2009; T. B. Lawrence & Suddaby, 2006; Wijen & Ansari, 2007; Zietsma & Lawrence, 2010), most empirical studies focus on the unidirectional effects from actors to the field or vice versa. Here, scholars have studied the actor’s actions and tools used to change the organizational field but the resources the actor acquires in return (cf. Lawrence, Leca, and Zilber, 2013; Raviola and Norbäck, 2013; Zietsma and Lawrence, 2010). However, since resources specific to one firm lead to heterogeneity rather than homogeneity of the organizational field (Deephouse, 1999), our research indicates that the process of institutional change might be affected by the fact that institutional entrepreneurs might gain firm-specific benefits. This finding further improves our understanding of the dynamism in the interaction between structure and agency (Deephouse, 1996; Hannan & Freeman, 1984; Pursey P. M. A. R. Heugens & Lander, 2009; T. B. Lawrence et al., 2013; Richard Scott, 1987; Zietsma & Lawrence, 2010). Third, this study further clarifies the motivation of firms conducting institutional entrepreneurship for non-proprietary technologies despite the fact that such a technology can also be used by free-riding competitors. This dissertation shows how institutional entrepreneurship can also lead to firm-specific benefits not available to free riders. This finding is in line with recent research from open innovation scholars, who showed that individuals participating in the development of open source software can gain individual benefits not available to free riders. However, the question of why a firm should participate in institutional entrepreneurship for non-proprietary technologies is as important as why an individual should do so because complex innovations require actions of organizations, not only individuals (Greenwood & Suddaby, 2006; Maguire et al., 2004; Überbacher, 2014). Our research confirms that benefits for individuals participating in the development of the non-proprietary technology are to a certain extent also applicable to firms. Unlike the benefits on the individual level, which can result from intrinsic (e.g. altruism, fun, kinship) and extrinsic (e.g. reputation, career, pay) motivations (Von Krogh et al., 2012), the benefits we found on the firm level are exclusively extrinsic as they were all used to facilitate the market launch of their own product.

For the strategic stakeholder management literature, the results of this dissertation can be seen as one of the first attempts to show detailed stakeholder management practices. They show how
nine different practice categories were conducted during the innovation development phase and whether each of these practices was rather conducted by the firm alone or in cooperation with other firms. As an implication, the results indicate the importance of the temporal dimension of strategic stakeholder management. Thus far, scholars have focused on the delineation of universal elements of strategic stakeholder management such as stakeholder identification, prioritization, and integration (e.g. Sharma and Vredenburg, 1998). When it comes to the detailed practices, however, strategic stakeholder management changes along time. For instance, at the beginning of the innovation phase, strategic stakeholder management was mainly used to develop basic technological knowledge and to set the industry standard. At the end of the innovation development phase, strategic stakeholder management was mainly used to facilitate the market launch of the firm’s own end product. Hence, the definition of what strategic stakeholder management exactly is needs to be adjusted to the temporal period of observation.

As a second implication, our results indicate that the question of who should conduct the practices – the firm alone or in cooperation with other firms – is an important one. When it comes to the resolution of stakeholder issues related to the overall technology, cooperative practices among many firms might be necessary due to the high complexity of the case. However, such cooperative practices are difficult to organize spontaneously. In the successful empirical cases, firms had built joint platforms or relationships in the earlier development phases. Hence, a proactive development of relationship and platforms even with competitors might be necessary for innovations, which might experience broad stakeholder issues in the later innovation stages.

5.2 Implications for policy makers

Paper I simulated the comparative cost efficiency of vehicles with electric and conventional powertrain technologies across three vehicle classes and three use cases for the German vehicle market. The results indicate that the cost efficiency of the innovative technology compared to the incumbent technology varies significantly across TCO cases. Moreover, our Monte Carlo simulations show that the statistical distributions of the possible outcomes overlap across technologies. Hence, the future comparative cost efficiency is still uncertain and can thus be influenced by policy measures. These insights lead to implications for the design of technology-push and demand-pull policies. Technology-push policies can be more effective by targeting the technological and economic factors that have a high impact on the future performance indicator. In our EV case, for example, policy measures targeting the battery manufacturing
cost would have a high impact on the comparative cost efficiency of the vehicle technologies. Our sensitivity analysis shows that the battery cost development has the second-highest impact on the TCO results of EV next to the vehicle glider cost. For demand-pull policies, we suggest policy measures which facilitate the consumers’ engagement in a more case-specific evaluation of the technology. Such an evaluation might help consumers that are situated in the relevant market segment to realize the high cost efficiency of the new technology. Hence, consumer education can nudge consumers towards the adoption of an innovation. In the EV case for instance, cost labels signaling the cost efficiency of vehicles per driving distance category and the establishment of a recognized online cost calculation platform are two possible measures of consumer education.

Paper II indicates that innovation policies can positively affect knowledge search and development of new technologies. However, this positive effect of technology-push and demand-pull policies can lead firms to narrow down their search scope in order to find faster solutions and reduce information overload. In addition, we found evidence that especially demand-pull policies may lead firms to reduce search for knowledge outside of their main technology domain. Therefore, the mix and intensity of technology-push and demand-pull policies require careful deliberation in order to avoid premature technological lock-ins.

5.3 Managerial implications

This dissertation informs managers responsible for the development and introduction of innovations mainly in three ways. First, our empirical observations suggest that a firm that mobilizes resources to legitimize non-proprietary technologies such as EV or nanotechnology can gain competitive advantage for its own end product (cf. paper III). Hence, although legitimization of a non-proprietary technology seems to be a costly job for the industry, it might also grant competitive benefits to the firm. This notion of competitive benefits was often intuited by the interviewed business unit managers. However, they could only elaborate their assumption to a limited extent and requested concrete explanations on what such benefits might be in order to have tangible explanations for their internal stakeholders. Our results provide such explanations. While it is difficult to directly track the financial benefits of legitimation, our framework in paper III hints at the resources such as networks, knowledge, and reputation, which can be tracked as intermediate benefits. In addition, our results also suggest the right timing when a manager should focus on the creation of such constructs. Without the explicit knowledge of these firm-specific resources, managers might be tempted to let competitors do
the costly work of legitimation and free ride on the established technology afterwards. In so doing, firms might be able to reap the fruit of the established technology, but not of the firm-specific resources and competitive differentiation only accessible to the firm which was engaged in the legitimation process.

Second, managers should change the focus between legitimation of the new technology and competitive differentiation of their own end products during the phases of innovation development. In an early stage, management focus should stay at the level of legitimation, which can naturally lead to the creation of resources which can be used for competitive differentiation. Later, management focus can shift towards competitive differentiation since the leverage of the created resources requires active management. For instance, the business unit managers need to call and collaborate with the toxicology department in order to accelerate the product approval process. Otherwise, the contacts and data development through the legitimation process might remain unutilized. To codify such active management, firms could develop guidelines or manuals on how to contact the managers in the departments responsible for the legitimation process (such as product approval, toxicology, or advocacy). On the legitimation management side, firms should entrench the practice of resource creation in the minds of the employees and provide systematic tools to track these resources. This can result in more conscious creation of firm-specific resources during the legitimation process.

Third, managers should proactively develop broad collaboration platforms with other firms (and even competitors) in the early phase of innovation development to create the opportunity for a later return from firm-individual practices to cooperative practices. Such cooperative practices can solve stakeholder issues related to the overall technology more effectively than firm-individual practices. My research shows that the active and early development of collaboration platforms was not yet conducted systematically. In the EV case for instance, the successful return to cooperative practices in the late phase of innovation development was based on platforms created by policy initiatives or incidental events. Therefore, a proactive development of early collaborations with other firms for the switch back to cooperative practices could contribute to a successful market launch, especially for innovations which experience high public or regulatory attention. More specifically, formal platforms (e.g. industry associations) and informal relationships (e.g. with firms along the value chain, competitors) based on collaborations in the earlier phases are observed to be important antecedents for organizing later cooperative practices (cf. paper IV).
5.4 Limitations and future research

This thesis has contributed to a better understanding of the different stakeholders involved in the development and market introduction of a new technology. Such an understanding is becoming increasingly important since business is becoming more and more entangled with its social environment including these different stakeholders (Carroll & Buchholtz, 2014). However, this dissertation can only cover certain aspects of the research required to advance our understanding of how new technologies can be developed and launched successfully with the consideration of different stakeholders. Given the limitations of this dissertation, the status of current research, and the practical challenge for policy makers and firms to develop and introduce new technologies, further research in this field is of importance. Thereby, two main avenues of research might build on this dissertation. The one avenue leads to more micro-level research of the firm based on the macro-level effects found in Papers I and II. The other avenue leads to the test of the generalizability of the firm implications found in Papers III and IV. Both avenues are discussed in the following.

More details on how different stakeholders react to policy can yield important implications for policy designers and managers. Papers I and II started to assess these details. Paper I focused on the assessment of the differences among consumer segments. The results indicate that these differences are significant and can be leveraged for more elaborated policy designs. However, the analysis of the paper has two main limitations. First, it only assesses one – albeit an important – evaluation criterion. However, studies have shown that certain evaluation criteria can have interaction effects (e.g., Babin et al., 1994). Hence, although cost has been confirmed as one of the main decision drivers by many studies (e.g., Al-Alawi & Bradley, 2013a; To et al., 2007), its isolated effect is not completely enough to derive comprehensive policy implications. Second, it does not explain the process of how different consumer segments evaluate. Hence, there are opportunities for future studies to include other utilitarian criteria such as environmental friendliness and convenience as well as hedonic criteria such as driving enjoyment and aesthetics of design. Also, the process of how consumers evaluate the new technology can shed light on the effectiveness of current policy instruments. Both aspects can be addressed through more in-depth research within and outside of the EV case. The EV case is appropriate for the assessment of consumer differences due to the complexity of the technology and the resulting multiplicity of potential consumer segments. Beside EV, however, there are other technologies with similar degrees of complexity and consumer diversity such as
building technologies or biodegradable products that can also serve as research cases. Paper II has two main limitations which might provide opportunities for further research. First, it is limited to the global PV industry, which has some conditions different to other industries. For instance, it is an industry intensively supported by policies, has in general a high degree of patent activities, and a high degree of knowledge spillovers across firms. While these conditions make the PV industry appropriate for our research question, they might lead to some results not applicable to all industries. Hence, future research should explore the generalizability of the results across industries. Second, our research does not examine the mechanisms inside the firm that lead to the findings. For example, it remains unexplored whether the reduction of search scope due to innovation policies results from faster finding of solutions, information overload, or higher opportunity cost of search. To explore these mechanisms connecting policies and firm search, more in-depth qualitative case research might be appropriate.

Papers III and IV assessed the firm-internal mechanisms in-depth through qualitative research. These papers have two main limitations. First, due to the nested case study approach within one firm, only a small number of samples was available. As a consequence, the selected cases might not all fit perfectly to the sample criteria and hence lead to lower construct validity. For instance, one could challenge that one technology assessed in Paper I is completely non-proprietary as it was only developed by very few firms globally. Hence, this technology per se could only be sold by these few firms and would be therefore quasi-proprietary. Second, the generalizability of the results remains to be tested. One way to test the generalizability would be variance research across a high number of non-proprietary innovation cases. Here, one could assess the performance variance between those firms acting as institutional entrepreneurs and those firms acting as free riders not engaged in institutional entrepreneurship. Since the innovations are non-proprietary and thus do not grant competitive advantage per se, a better performance by institutional entrepreneurs over free riders would support the resource effects found in my research. Another more detailed way to increase the generalizability of my results would be the inclusion of more case studies. Building on the constructs found regarding resources and stakeholder management practices, further research could conduct systematic cross-case comparisons with the analytic induction method (Manning, 1982). In this way, not only the generalizability but also the internal and construct validity could be further tested and refined. These are only two exemplary ways. In addition, mixed-method approaches are potentially suitable. The choice of method strongly depends on the desired scope of the theory contribution.
Quantitative research might be better suited to test the theory for a broad scope of innovations. For instance, it is conceivable that institutional entrepreneurs for non-environmental or even process innovations could gain the same resource benefits. Qualitative case comparisons are better suited for testing the theory for a very specific set of innovations. In my research, we specifically conducted theoretical sampling of cases which were in need of legitimation, refer to an environmental aspect, and are publicly visible. In case future research aims at improving the theory for such specific sets of innovations, more cases studies might be more fruitful than quantitative studies, also because of the low number of suitable samples.
6 Overview of papers

Table 5. Overview of the papers included in this dissertation

<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>Authors</th>
<th>Journal</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments</td>
<td>Wu, G. Inderbitzin, A. Bening, C.</td>
<td>Energy Policy</td>
<td>Published</td>
</tr>
<tr>
<td>II</td>
<td>The impact of demand-pull and technology-push policies on firms’ knowledge search</td>
<td>Hoppmann, J. Wu, G. Hughes, J.</td>
<td>Targeted toward Academy of Management Journal</td>
<td>Working paper</td>
</tr>
<tr>
<td>III</td>
<td>From institutional entrepreneurship to differentiation advantage: How firm-specific benefits can emerge from legitimation of non-proprietary technologies</td>
<td>Wu, G. Hamprecht, J. Bening, C</td>
<td>Journal of Management Studies</td>
<td>Accepted for revision</td>
</tr>
<tr>
<td>IV</td>
<td>The process of strategic management of secondary stakeholders: Evidence from four innovation cases</td>
<td>Wu, G. Hamprecht, J. Bening, C</td>
<td>Targeted toward California Management Review</td>
<td>Working paper</td>
</tr>
</tbody>
</table>
References


Annex I – individual papers
Paper I
Published in Energy Policy, 80: 196-214. doi:10.1016/j.enpol.2015.02.004

**Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments**

Geng Wu*, Alessandro Inderbitzin, Catharina Bening

ETH Zurich, Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56/58, Zurich, CH-8092, Switzerland

* Corresponding author contact details:

gwu@ethz.ch

Phone: +49 175 318 9190
Abstract

While electric vehicles (EV) can perform better than conventional vehicles from an environmental standpoint, consumers perceive them to be more expensive due to their higher capital cost. Recent studies calculated the total cost of ownership (TCO) to evaluate the complete cost for the consumer, focusing on individual vehicle classes, powertrain technologies, or use cases. To provide a comprehensive overview, we built a probabilistic simulation model broad enough to capture most of a national market. Our findings indicate that the comparative cost efficiency of EV increases with the consumer’s driving distance and is higher for small than for large vehicles. However, our sensitivity analysis shows that the exact TCO is subject to the development of vehicle and operating costs and thus uncertain. Although the TCO of electric vehicles may become close to or even lower than that of conventional vehicles by 2025, our findings add evidence to past studies showing that the TCO does not reflect how consumers make their purchase decision today. Based on these findings, we discuss policy measures that educate consumers about the TCO of different vehicle types based on their individual preferences. In addition, measures improving the charging infrastructure and further decreasing battery cost are discussed.

Keywords: electric vehicles; technology transfer; cost comparison; total cost of ownership; transport sector
1. Introduction

1.1. Total cost of ownership of electric vehicles

The transport sector can strongly contribute to the alleviation of greenhouse gas emissions (Kley, Lerch, & Dallinger, 2011; Kotter, 2013; Shafiee & Topal, 2009). In the European Union (EU) for instance, passenger cars and vans currently emit around 15 per cent of total carbon dioxide (CO₂) emissions (European Commission, 2014b). Hence, policy makers have set transport regulations (e.g. California Corporate Average Fuel Economy standards, European Union transport regulations) to reduce CO₂ emission from vehicles. Since these regulations consider the tailpipe, not the well-to-wheel emissions (European Commission, 2014b), purely electric vehicles (EV) count as zero emission cars. The automotive industry has further developed EV through hybrid or pure electric powertrains, an effort partly supported by national and regional policy initiatives. California, for instance, initiated the Clean Vehicle Rebate Project, which offers up to 5,000 USD rebate for the private purchase of an EV in addition to federal tax credits of 7,500 USD. But how cost-efficient for the consumer are EV without subsidies? Despite the advantages of lower CO₂ emission per km when combined with renewable energy and less dependence on fossil fuels (Hawkins, Singh, Majeau-Bettez, & Strømman, 2013; Thiel, Perujo, & Mercier, 2010), EV have the disadvantage of being perceived as more expensive than conventional vehicles. This perception might stem from the higher capital cost being easier for consumers to evaluate than the operating cost (Contestabile, Offer, Slade, Jaeger, & Thoennes, 2011). However, existing studies show that the operating cost can actually be lower for EV than for conventional vehicles (e.g. Propfe and Redelbach, 2012). In order to compare the cost for consumers more comprehensively, including both capital and operating cost, researchers have applied the total cost of ownership (TCO) calculation method (e.g. Lin et al., 2013; Thiel et al., 2010; Tseng et al., 2013).

Table 1 presents the core studies in this area. Delucchi and Lipman (2001, 2006) were among the first to use technical and economic input parameters to determine the lifetime cost of EV. Their studies calculated the cost for the current year, focusing on one specific powertrain technology and consider single reference models not representing the vehicle class. Later, Thiel, Perujo, and Mercier (2010) included several powertrain technologies as well as a future

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1 Tailpipe emission only takes emissions from the onboard source of power of a vehicle into account, whereas well-to-wheel emission also takes the emissions produced in the process of energy provision into account.
extrapolation of the cost. Their study, however, neither considered the projection of the technical parameters (e.g., battery depth of discharge) nor the impact of use cases. This lack of use case consideration was also observed in many recent studies, which mostly also do not address the stochastic nature of input parameters (e.g. Al-Alawi and Bradley, 2013; Tseng et al., 2013). A more comprehensive model can be found in a report from the Fraunhofer institute (Plötz et al., 2013). This model does simulate various use cases, vehicle classes, and powertrain technologies. However, whereas it considers the variance of some main input parameters (e.g. the current range of different driving distances), it does not simulate the uncertainty of the projections of capital cost and technical parameters. Hence, we conclude from our review that existing studies have different methodological approaches and tend to lack the comprehensiveness in regards to powertrain technology, vehicle class, use case, or the stochastic nature of input parameters.

The existing studies indicate that, without federal support, EV are currently more expensive than ICEV, but are likely to become more cost-efficient in the near future. However, the inconsistency of the methodological approach among these studies makes their detailed results difficult to compare and hence prevents a market wide meta-analysis of the TCO/km. For instance, whereas Prud’homme and Koning (2012) calculated a present TCO cost disadvantage of over EUR 12,000 for BEV compared to ICEV, this gap is below EUR 7,000 in all scenarios of Tseng et al. (2013)\(^2\). Therefore, a better understanding of the TCO of electric vehicles comprehensively across the market seems advisable.

\(^2\)There are obvious reasons for this discrepancy such as difference in regional focus, vehicle class focus, and time of analysis. Hence we show this comparison only to exemplify the difficulties in combining current studies for a market overview, not to criticise the results themselves.
Table 1. TCO literature review.

<table>
<thead>
<tr>
<th>Source</th>
<th>Model type</th>
<th>Powertrain technology focus</th>
<th>Vehicle classes covered</th>
<th>Use case consideration</th>
<th>Future extrapolation</th>
<th>Sensitivity/uncertainty analysis</th>
<th>Reference country</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Wu, Dong, &amp; Lin, 2014)</td>
<td>Mainly economic</td>
<td>PHEV</td>
<td>C/D (single reference models)</td>
<td>Yes</td>
<td>No</td>
<td>No/No</td>
<td>USA</td>
</tr>
<tr>
<td>(Al-Alawi &amp; Bradley, 2013b)</td>
<td>Techno-economic</td>
<td>PHEV</td>
<td>Compact, Midsize, Midsized SUV, Large SUV</td>
<td>No</td>
<td>No</td>
<td>Yes/No</td>
<td>USA</td>
</tr>
<tr>
<td>(C. Lin et al., 2013)</td>
<td>Techno-economic</td>
<td>ICEV-SI, HEV</td>
<td>SUV (Single reference models)</td>
<td>No</td>
<td>No</td>
<td>Yes/No</td>
<td>China</td>
</tr>
<tr>
<td>(Plötz et al., 2013)</td>
<td>Mainly economic</td>
<td>ICEV-SI, ICEV-CL, PHEV, REEV, BEV</td>
<td>Small, Medium, Large (Category of reference models)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes/Yes</td>
<td>DE</td>
</tr>
<tr>
<td>(Tseng et al., 2013)</td>
<td>Economic</td>
<td>ICEV-SI, HEV, PHEV, BEV</td>
<td>Midsize vehicles (Single reference models)</td>
<td>No</td>
<td>No</td>
<td>Yes/No</td>
<td>USA</td>
</tr>
<tr>
<td>(Hill, Varma, Harries, Norris, &amp; Kay, 2012)</td>
<td>Techno-economic</td>
<td>ICEV-SI, ICEV-CL, HEV, REEV, BEV</td>
<td>C/D, Van (Representative average)</td>
<td>No</td>
<td>Yes</td>
<td>No/No</td>
<td>UK</td>
</tr>
<tr>
<td>(Prud’homme &amp; Koning, 2012)</td>
<td>Mainly economic</td>
<td>ICEV-CL, BEV</td>
<td>A/B (single reference model)</td>
<td>No</td>
<td>(Yes)</td>
<td>Yes/No</td>
<td>FR</td>
</tr>
<tr>
<td>(Bickert &amp; Kuckshinrichs, 2011)</td>
<td>Techno-economic</td>
<td>ICEV-SI, REEV, BEV</td>
<td>Micro, Subcompact, Compact (single reference vehicle)</td>
<td>No</td>
<td>Yes</td>
<td>Yes/No</td>
<td>DE</td>
</tr>
<tr>
<td>(Contestabile et al., 2011)</td>
<td>Techno-economic</td>
<td>ICEV-CL, HEV, PHEV, BEV, FCEV</td>
<td>Super-mini, Lower-medium, Multipurpose, Luxury (Single reference models)</td>
<td>No</td>
<td>Yes</td>
<td>Yes/No</td>
<td>UK</td>
</tr>
<tr>
<td>(Thiel et al., 2010)</td>
<td>Mainly economic</td>
<td>ICEV-SI, ICEV-CL, HEV, PHEV, BEV</td>
<td>Midsize vehicle (Single reference models)</td>
<td>No</td>
<td>Yes</td>
<td>Yes/No</td>
<td>EU-27</td>
</tr>
</tbody>
</table>
1.2. Further understanding TCO of electric vehicles

The existing TCO studies mentioned above have often focused on a single aspect (e.g. vehicle class or driving distance) and most apply deterministic input parameters. However, a comprehensive, probabilistic view is important for two reasons. First, it provides a more complete understanding of whether and in which case the political will to support a market transition towards EV is mirrored by cost efficiency for consumers. A lack of such a wide-ranging view can lead to forfeit opportunities or missed policy targets as past studies have shown (e.g. Arocena et al., 1999; Peters et al., 2012). Second, since many of the important input parameters, such as fuel, electricity, and battery cost development, are uncertain, results showing the probabilities and distributions of possible outcomes might be more appropriate than deterministic rankings or figures. With such a probabilistic view, the ease of understanding whether policy measures can potentially affect the comparative cost efficiency of different technologies could be enlarged. This study aims to provide such a comprehensive, probabilistic view by asking: How does the total cost of ownership of electric vehicles compare to that of conventional vehicles across the major vehicle classes and driving distance cases? We aim to answer this question from the consumer’s perspective and hence consider the cost positions occurring to the consumer during his or her ownership period.

To answer our research question, we calculated and compared the discounted TCO per kilometer (TCO/km) among internal combustion engine (ICEV), hybrid electric (HEV), plug-in hybrid (PHEV), and battery electric vehicles (BEV). The outcomes were calculated for the years 2014, 2020 and 2025 using Monte Carlo simulations. Thereby, we used input data from

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3 Uncertain TCO with overlapping outcome distributions among technologies indicate that policy measures will have the potential to influence the comparative TCO ranking of these technologies. In contrast, clearly determined TCO among technologies with distinct outcome distributions indicate that policy measures will have less potential to influence the comparative TCO ranking of these technologies.
multiple sources and used the statistical distribution among these data to calculate the ranges and averages of the TCO outcomes. We tested our outcomes with multiple rounds of simulations (with 10,000 iterations per simulation). Since all the simulations yield very similar results (with a maximum deviation of 3% among the comparable outcomes), we see our approach as a reliable way to conduct the analyses with the existing data. In addition, we include a sensitivity analysis showing the variables with the highest effect on the outcome. Hence, if the input values change in the future, the possible impact on the results can be deducted. Since this study exclusively focuses on cost, which is just one of many factors determining the buying decision of a consumer, our modelling approach should be seen as a way to understand the cost factor in detail and to generate inputs rather than as an alternative to comprehensive market modelling approaches such as agent-based simulations or consumer choice models (Al-Alawi & Bradley, 2013a).

This paper is structured as follows. In the next section, we present our methodology. Subsequently, we show the mean TCO/km results, the distribution of possible TCO/km results, the probability of occurrence of our TCO/km outcomes, and the sensitivity analysis. We conclude this paper with a discussion of the results, policy implications, and limitations.

2. Methodology

2.1. Scope and data basis of TCO analysis

We calculated TCO outcomes for the following years: 2014, 2020, and 2025. These years are interesting due to corresponding policy targets (e.g. EU transport regulations, German vehicle stock target 2020), and are also still in the scope of many other studies providing us input data for our projections (e.g. Cluzel and Douglas, 2012; Plötz et al., 2013; Santini et al., 2010). To consider cost efficiency from the perspective of a consumer, we calculate the costs occurring to the first vehicle owner, which is the decisive consumer for the market diffusion of the vehicle⁴. Regarding the geographical focus, we set country boundaries because cost positions highly depend on the country specifics (e.g. electricity prices, fuel prices, taxes, insurances). We conducted the case for Germany due to the national importance of this topic and the

---

⁴ The resale value of the vehicle after the holding period of the first owner is taken into account and explained in more detail in the method section. This ownership cost assessment of the first owner is different to a lifetime cost assessment of a vehicle, which would include all costs from production to scrappage as well as environmental and societal costs (cf. Tseng et al., 2013).
availability of data. The German automotive industry has a high economic and political relevance, evidenced by the sector’s contribution of 10% to the gross domestic product (VDA, 2014), which is significantly higher than the EU average, and the relevance of vehicles for the social status of the owner (Zubaryeva, Thiel, Zaccarelli, Barbone, & Mercier, 2012). Further, Germany has by far the biggest country stock of passenger cars within the EU with all car brands and powertrain technologies on the market (International Council on Clean Transportation, 2013). In addition, German original equipment manufacturers (OEM) have introduced several electrified vehicles accompanied by policy makers launching innovative platforms to support the EV transition during the past six years (e.g. German National Platform for Electric Mobility since 2008), which allows us to contact experts to validate our EV assumptions. Within Germany, our model calculates the TCO/km along three dimensions: powertrain technology, vehicle class, and use case.

First, concerning powertrain technologies, we included ICEV and HEV\(^5\) as conventional vehicles. For the ICEV, we included vehicles with spark ignition (ICEV-SI) engines, which are fueled by gasoline, and compression ignition (ICEV-CI) engines, which are fueled by diesel. Vehicles with electric powertrains are categorized into plug-in hybrid electric vehicles (PHEV) and battery electric vehicle (BEV)\(^6\).

**Table 2. Description of powertrain categorization.**

<table>
<thead>
<tr>
<th></th>
<th>Conventional powertrain</th>
<th>Electric powertrain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICEV</td>
<td>HEV</td>
</tr>
<tr>
<td>Degree of electrification</td>
<td>No electric engine infrastructure</td>
<td>Low (only to increase fuel economy of ICEV)</td>
</tr>
<tr>
<td>Primary propulsion</td>
<td>ICE</td>
<td>ICE</td>
</tr>
<tr>
<td>Electric range (in Km)</td>
<td>0</td>
<td>~ 5</td>
</tr>
<tr>
<td>Main electric charging source</td>
<td>Not needed</td>
<td>Braking energy recuperation</td>
</tr>
</tbody>
</table>

\(^5\) A HEV contains a parallel hybrid configuration of a large ICE, which is the primary source of movement, and a small electric drive for efficiency improvement.

\(^6\) Both types of vehicle have the electric motor as primary source of propulsion. However, whereas a BEV powertrain operates purely electrically, a PHEV powertrain still contains a small ICE.
Second, concerning vehicle classes, we follow the categorization of the European Commission, which subdivides passenger vehicles into different market segments according to technical and size-related characteristics of the vehicle (European Commission, 1999). Out of the nine original classes, we included the five classes which are commonly considered most relevant for EV and represent in total approximately 78% of the new vehicles sold in Germany (International Council on Clean Transportation, 2013; Kraftfahrt-Bundesamt, 2013a). In line with most of the existing reports and studies (e.g. Douglas and Stewart, 2011; Plötz et al., 2013; Prud’homme and Koning, 2012), we further aggregated these five classes into the A/B, representing the small vehicles, C/D, representing the medium vehicles, and J class, representing the large vehicles. Table 3 summarizes our vehicle class definition.

Table 3. Description of vehicle classes.

<table>
<thead>
<tr>
<th>Source</th>
<th>A/B</th>
<th>C/D</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>Mini (A) and small (B) vehicles</td>
<td>Lower medium (C) and medium (D) vehicles</td>
<td>Sport utility vehicles (Kraftfahrt-Bundesamt, 2013b)</td>
</tr>
<tr>
<td>Exemplary cars</td>
<td>Smart ForTwo, Fiat Panda, VW Polo, Mini Cooper</td>
<td>VW Golf, Audi A3, BMW 3-series, Mercedes-Benz C-class</td>
<td>BMW X3, Nissan Qashqai, VW Tiguan</td>
</tr>
<tr>
<td>Share of new registrations</td>
<td>23.3%</td>
<td>38.2%</td>
<td>15.7%</td>
</tr>
</tbody>
</table>

Third, concerning use cases, we derived our parameters from the 2008 German mobility study (infas & DLR, 2008), which, in line with existing literature, indicates that driving distance is by far the most important segmentation parameter for use cases. Table 4 shows the three distances, representing the average annual mileage for the three use cases, we applied for our study. There appears to be a contradiction of long distance and the limited EV driving range, but, in reality, the required driving distance without charging interruption rarely exceeds the electric range. For instance, less than 5% of private consumers have a regular daily commuting distance of over 50 km (Statista, 2014b). The average BEV can easily travel 150 to 200 km without charging (Table 2). Even our long distance cases only presume a total daily driving distance of 78 km. However, as one main limitation, we acknowledge that there are peak distances in daily travelling exceeding the range of 200 km (e.g. vacation travel), which are not considered. As a second limitation, we used the electric range and the average daily driving distance per use case to calculate the share of electric driving of a PHEV. In reality, however,
the variance of daily travel distance over a year leads to different shares of electric driving (Plötz et al., 2013).

Table 4. Use case parameters.

<table>
<thead>
<tr>
<th></th>
<th>Short distance</th>
<th>Medium distance</th>
<th>Long distance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily mileage (in km)</td>
<td>20.5</td>
<td>41.6</td>
<td>77.9</td>
<td>(infas &amp; DLR, 2008; Statista, 2014c)</td>
</tr>
<tr>
<td>Annual mileage (in km)</td>
<td>7,483</td>
<td>15,184</td>
<td>28,434</td>
<td></td>
</tr>
<tr>
<td>Share of drivers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Range of mileage included)</td>
<td>47.2% (0 – 10,000km)</td>
<td>41.0% (10,000-20,000 km)</td>
<td>11.8% (&gt;20,000 km)</td>
<td></td>
</tr>
</tbody>
</table>

In conclusion, our scope of analysis includes the TCO examination of each combination out of four powertrain technologies, three vehicle classes, and three use cases. In the following, we refer to each combination as one TCO case.

The input data for the analyses were derived from reviewing relevant literature including peer-reviewed journal contributions, reports by research and industrial associations, and empirical data (e.g. from German federal motor transport authority). For crucial input factors such as battery cost or the projections of parameters until 2025, we also validated our data through expert interviews with German OEMs associated with leading EV development as well as two major suppliers of battery materials.

2.2. TCO model

We calculated the total TCO of the new vehicle divided by the total distance (in km) driven for the new vehicle owner resulting in the TCO/km. Thereby, future costs are discounted to their present values. The following equation summarizes our calculation approach:

\[
TCO / km = \frac{(IPC - RV \times PVF) \times CRF + \frac{1}{N} \sum_{n=1}^{N} \frac{AOC}{(1+i)^n}}{AKT}
\]

We derived the capital cost by deducting the present value of the future resale value (RV) from the initial purchase price (IPC), annualized by the capital recovery factor (CRF), which determines the annual repayment, which is required for the purchase of a vehicle based on an assumed discount rate. The average annual operating cost (AOC) takes the time value of future
payments with a discount rate into account. This present value of annual cost was then divided by the annual kilometers travelled (AKT). The parameters RV, IPC, AOC, and AKT are all dependent on the vehicle class and use case and will be explained later in more detail.

The parameters CRF, i, N, and PVF are assumed to be the same for all cases. For N, we assume an average vehicle holding period of six years, which is the current average holding period among private owners of passenger cars in Germany (RWTH Aachen, 2012). For the calculation of CRF and PVF, we used this holding period of six years and an interest rate i of 4.1%, which is the current interest rate of provisions with residual maturity of 6 years (Deutsche Bundesbank, 2014). We assumed the same discount rate for all technologies which is in line with the current market observations\textsuperscript{7}.

The capital cost is the IPC less the present value of the RV of the vehicle after the holding period (Figure A.1). For ICEV, we could derive the range of IPC per vehicle class statistically from available market data. The vehicles sold per year included all brands and models per brand in the respective vehicle class. We always took the lowest list price per model. For HEV, PHEV, and BEV, empirical data were insufficient or not representative due to the low number of vehicles sold. Hence, we calculated the initial purchase price for HEV, PHEV, and BEV bottom-up. We first used technical parameters to derive the required battery capacity. This capacity together with the cost per capacity leads to the total cost of the battery cells (Tables 5 and 6). We added other battery cost positions such as pack integration and thermal management cost in order to derive the total cost of the battery (Table A.1). This battery cost was added to the cost of other powertrain components and the glider cost to complete the total vehicle cost calculation. All cost positions also included the associated indirect costs. On top of these costs, we added an average profit margin retrieved from literature and validated in our interviews (Cambridge Econometrics & Ricardo - AEA, 2013)\textsuperscript{8}. Due to lack of used EV in the market, the empirical data were insufficient to derive the RV of an EV. Hence, we applied a mathematical approach using a hedonic price index according to Dexheimer (2003), which takes into account

\textsuperscript{7} It is possible that OEM introduce different discount rates (e.g. for leasing). However, our sensitivity analysis shows that the discount rate would not be one of the 10 parameters with the highest impact on the results.

\textsuperscript{8} We assumed a profit margin of 0\%, 12.2\%, and 15.2\%, for 2014, 2020, and 2025 respectively for PHEV and BEV. For HEV, we assumed a constant profit margin of 24.3\%, which is the same as the average margin of an ICEV.
the driven kilometers, the holding period, and the initial purchase price of the vehicle assuming a degressive value depreciation.

Table 5. Key battery size parameters in 2014.

<table>
<thead>
<tr>
<th></th>
<th>HEV</th>
<th>PHEV</th>
<th>BEV</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated electric range (in km)</td>
<td>5</td>
<td>60</td>
<td>160</td>
<td>(National Research Council, 2013; Propfe &amp; Schmid, 2011)</td>
</tr>
<tr>
<td>Battery depth of discharge (in %)</td>
<td>50</td>
<td>60</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Derived Battery Size for A/B segment (in rounded kWh)</td>
<td>0.6</td>
<td>14</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Derived Battery Size for C/D segment (in rounded kWh)</td>
<td>0.8</td>
<td>25</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Derived Battery Size for J segment (in rounded kWh)</td>
<td>1</td>
<td>34</td>
<td>58</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Battery manufacturing cost depending on size in 2014.

<table>
<thead>
<tr>
<th>Size (in kWh)</th>
<th>1</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (in EUR/kWh)</td>
<td>1080</td>
<td>691</td>
<td>588</td>
<td>524</td>
<td>479</td>
<td>445</td>
<td>419</td>
<td>397</td>
<td>379</td>
<td>363</td>
<td>337</td>
</tr>
</tbody>
</table>


The AOC was derived from the energy consumption cost and other cost positions such as vehicle taxes, insurance, repair and maintenance, and parking fees (Figure A.2). Table 7 shows the key input parameters with the values derived from literature or public reports. For PHEV, we distinguished between the charge sustaining driving (PHEV-CS), which is the consumption of fuel with the ICE, and the charge depletion driving (PHEV-CD), which is the consumption of electricity using the electric engine. The energy consumption costs represent the calculated averages of the consumption data of the vehicles within each class. In addition to the average consumption data from the New European Driving Cycle (NEDC), we included a real-world consumption uplift to consider the fact that a private consumer rarely meets the energy consumption of the NEDC tests (Hill et al., 2012). In general, we assume that the battery life of all vehicles exceeds our holding period of six years. This assumption is in line with the assumption of the OEM such as BMW or Opel, which provide a EV battery warranty of 8 years, and is comparable to recent EV tests, which result in a predicted battery life of at least 160,000 km for an average driver (Demmerle, 2014).

Table 7. Key operating cost parameters in 2014.

<table>
<thead>
<tr>
<th>ICEV-SI</th>
<th>ICEV-CI</th>
<th>HEV</th>
<th>PHEV-CS</th>
<th>PHEV-CD</th>
<th>BEV</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICEV-SI</td>
<td>ICEV-CI</td>
<td>HEV</td>
<td>PHEV-CS</td>
<td>PHEV-CD</td>
<td>BEV</td>
<td>Sources</td>
</tr>
</tbody>
</table>

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### Table

<table>
<thead>
<tr>
<th>Consumption per 100km A/B</th>
<th>5.18 L</th>
<th>3.97 L</th>
<th>4.40 L</th>
<th>5.18 L</th>
<th>13.78 kWh</th>
<th>13.78 kWh</th>
<th>(Kraftfahrt-Bundesamt, 2013b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption per 100km C/D</td>
<td>6.19 L</td>
<td>4.72 L</td>
<td>5.26 L</td>
<td>6.19 L</td>
<td>20.67 kWh</td>
<td>20.67 kWh</td>
<td>(Ward, Moawad, Kim, &amp; Rousseau, 2012)</td>
</tr>
<tr>
<td>Consumption per 100km J</td>
<td>7.31 L</td>
<td>6.12 L</td>
<td>6.22 L</td>
<td>7.31 L</td>
<td>25.59 kWh</td>
<td>25.59 kWh</td>
<td>(Propfe &amp; Redelbach, 2012)</td>
</tr>
<tr>
<td>Fuel/energy consumption price</td>
<td>1.59 EUR/L</td>
<td>1.43 EUR/L</td>
<td>1.59 EUR/L, 0.29 EUR/kWh</td>
<td>1.59 EUR/L, 0.29 EUR/kWh</td>
<td>0.29 EUR/kWh</td>
<td>0.29 EUR/kWh</td>
<td>(e.g. Bunderverband der Energie- und Wasserwirtschaft e. V. (BDEW), 2013)</td>
</tr>
<tr>
<td>Real-world uplift</td>
<td>19.5%</td>
<td>19.5%</td>
<td>21.7%</td>
<td>23.1%</td>
<td>24.6%</td>
<td>24.6%</td>
<td>(Hill et al., 2012)</td>
</tr>
<tr>
<td>Other costs (e.g., taxes, maintenance, insurance, parking, registration)</td>
<td>2,000 – 3,000 EUR per year (present value, depending on use case and vehicle)</td>
<td>(e.g. Propfe et al., 2012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2.3. Probabilistic model

The uncertainty of input parameters was taken into account for the initial values in 2014 as well as the projection of these values until 2025. This section first describes our projected mean values and subsequently presents the statistical distribution around them.

For the capital cost projection, we considered four key powertrain components: vehicle battery, electric motor system, engine and transmission, and on-board battery charger. The assumptions are based on expert forecasts from various reports and are presented in the Tables 8 and 9. For the projection of the vehicle battery price for instance, we reviewed 19 reports from industry associations, consulting firms, banks, and scientific institutions and used the minimum, average, and maximum cost decrease estimations, which were then the basis for our statistical distribution of the projections. In summary, we concluded from our data that the costs of battery and electric motor are likely to decrease mainly due to economies of scale and technology improvements. In contrast, we expect engine and transmission costs to increase due to improvements needed for fuel consumption and CO₂ emission reduction. These costs

---

9 In the case of battery price projection until 2020 for instance, the Electric Coalition projects a yearly price decrease of 16.37%, whereas the International Energy Agency only projects a yearly price decrease of 3.36%. These extreme values were taken as the minimum and maximum boundaries for the PERT distribution.
improvements include start-stop capabilities, turbocharging, gasoline direct injection, variable value timing, dual-clutch transmission, and ICE-aftertreatment.

Table 8. Key assumptions for capital cost projection.

<table>
<thead>
<tr>
<th></th>
<th>Yearly change (CAGR) in percentage</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric motor system</td>
<td>-4.40</td>
<td></td>
</tr>
<tr>
<td>Engine and transmission</td>
<td>+0.69</td>
<td></td>
</tr>
<tr>
<td>On-board battery charger</td>
<td>+1.90</td>
<td></td>
</tr>
</tbody>
</table>

For the operating cost projection, we mainly considered energy prices as well as technological advancements in the fuel economy. The gasoline, diesel, and electricity price projections are derived from the averages of existing forecasts and a own regression analysis based on price developments from 1998 until 2013 (BDEW, 2013; Mineralölwirtschaftsverband e. V., 2014)\textsuperscript{10}. The improvements in fuel and electricity economy are derived from literature (Plötz et al., 2013).

Table 9. Key assumptions for operating cost projection.

<table>
<thead>
<tr>
<th></th>
<th>Yearly change (CAGR) in percentage</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline price</td>
<td>+4.6</td>
<td>(BDEW, 2013; Mineralölwirtschaftsverband e. V., 2014; Plötz et al., 2013)</td>
</tr>
<tr>
<td>Diesel price</td>
<td>+6.2</td>
<td></td>
</tr>
<tr>
<td>Electricity retail price</td>
<td>+5.3</td>
<td></td>
</tr>
<tr>
<td>Improvements in fuel economy</td>
<td>+1.5</td>
<td></td>
</tr>
<tr>
<td>Improvements in electricity economy</td>
<td>+1.2</td>
<td></td>
</tr>
</tbody>
</table>

We then applied a simulation, a Monte Carlo method that uses the repeated simulation of output variables with probabilistic input values within a defined stochastic distribution per input variable (Jacoboni & Reggiani, 1983). For this study, we ran 10,000 simulations for each of the years 2014, 2020, and 2025.

\textsuperscript{10} For electricity, we put more weight on the recent data in order to reflect the price increases resulting from the German Renewable Energy Act, which is likely to lead to further politically induced price increases in the future (Haller, Hermann, Loreck, Matthes, & Cook, 2013).
We made use of four types of distributions (with the rationale presented in Table A.2). For the distribution of the values used for the cost calculation of the year 2014, we used the PEARSON distribution for those parameters for which we had empirical data\(^{11}\) and the Beta distribution for parameters which cannot have negative values. For the projections in 2020 and 2025, we used the PERT distribution for the yearly change of those parameters for which we included expert opinions to validate our assumptions and the normal distribution for the annual development of the yearly improvement in fuel economy and electric energy usage. Table 10 presents the distribution parameters for the probabilistic simulation. The simulations took possible correlations among input parameters into account (Table A.3). For instance, we correlated fuel and electricity prices based on correlations from historical data as well as the ICEV purchase price and the glider price projections in the future.

\(^{11}\) We used the Alpha, Beta, and Riskshift settings to adjust the PEARSON distribution as precisely as possible to the empirical distribution. For the vehicle price for instance, we gathered the option-adjusted list price of all vehicles within the relevant vehicle class. The statistical distribution of the data was then the model for the settings of the PEARSON parameters.
Table 10. Stochastic parameters for Monte Carlo simulation.

<table>
<thead>
<tr>
<th>Distributions</th>
<th>Parameter category</th>
<th>Input parameter</th>
<th>Distribution parameters</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAR-SON</td>
<td>Capital cost in 2014</td>
<td>Vehicle price (only ICEV) in 2014</td>
<td>Alpha 10.15 Beta 4.42 Riskshift 0.48</td>
<td>(Kraftfahrt-Bundesamt, 2013b)</td>
</tr>
<tr>
<td></td>
<td>Operating cost in 2014</td>
<td>Vehicle energy consumption in 2014</td>
<td>Alpha 16.39 Beta 2.28 Riskshift 0.84</td>
<td></td>
</tr>
</tbody>
</table>

| BETA          | Operating cost in 2014 | Other cost positions (e.g. engine and transmission, electric motor system, on board battery charger, and battery cell) | Min 0 Max 2 Alpha 50 Most likely 1 Alpha 2 50 | (Cluzel and Douglas, 2012; Deutsche Automobil Treuhand GmbH (DAT), 2012) |

| PERT          | Capital cost projection | Yearly change in battery price 2020 vs. 2014 | Min -16.37% Max -3.36% | (Cluzel & Douglas, 2012; Plötz et al., 2013; Santini et al., 2010) |
|               | Operating cost projection | Yearly change in gasoline price 2025 vs. 2020 | Min -9.81% Max -2.36% |
|               | Yearly change in diesel price | 3.81% | Min 3.81% Max 5.65% | (Mineralölwirtschaftsverband e. V., 2014) |
|               | Yearly change in electricity price | 4.87% | Min 4.87% Max 7.11% |

<table>
<thead>
<tr>
<th>Normal</th>
<th>Operating cost projection</th>
<th>Yearly improvement in fuel economy</th>
<th>Sigma 10%</th>
<th>(Plötz et al., 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yearly improvement in electricity economy</td>
<td>3.52%</td>
<td>Min 3.52% Max 5.49%</td>
<td></td>
</tr>
</tbody>
</table>

The Monte Carlo simulation enables two analyses in addition to the statistical distribution of the TCO. First, we could estimate the probability of a technology of having the lowest TCO for each TCO case at each point of time. For that, we calculated the relative share of the technologies with the lowest TCO in all 10,000 simulations in the respective years. Second, we could conduct a statistical sensitivity analysis. Thereby, we analyzed the variance of the 10,000 simulated outcomes based on the variance of variables. This effect is presented as a range around the mean value caused by the variance of one variable.

3. Results

3.1. Analysis of the medium distance, C/D case
In order to exemplify the steps of our analyses, we choose to present the medium distance, C/D vehicle case first before showing the results for all cases in the next subsection. As for all the cases, we conducted three analyses (Figure 1). The first analysis on the left hand side is the comparison of the mean TCO/km over time. In this case, the cost discrepancy between an ICEV and BEV converges from approx. 12 ct./km in 2014 to 3 ct./km in 2025. The next analysis in the middle of Figure 1 shows that the stochastic nature of the input parameters leads to a certain distribution of the results and hence to the overlap of outcomes12. For instance, the TCO/km range of ICEV includes all possible TCO/km outcomes of HEV. Hence, the ranking of the mean value may not reflect the actual ranking. That is why we conducted the third analysis to show a probability, rather than a deterministic ranking, of one technology having the lowest TCO/km. In this case, HEV and ICEV have a 51 and 40 per cent probability respectively to become the technology with the lowest TCO/km13. Even PHEV and BEV have a chance, albeit a small one, to be the most economic technology.

For this TCO case, we mainly conclude that the cost discrepancies among all technologies will converge significantly. However, it is not likely that EV become more economic than ICEV or HEV until 2025. This picture however differs among TCO cases, as shown in the next section.

---

12 The result variance of approximately 10% to 20% around the mean value is comparable to that of other reports (e.g. Douglas and Stewart, 2011). The lower variance for EV than for ICEV is a result of the more accurate projections for battery price development (which is decisive for EV TCO) than for the general vehicle price development for ICEV.

13 This means that in approximately 5,100 and 4,000 of the 10,000 simulations, HEV and ICEV had the lowest TCO/km respectively.
3.2. Analysis of all cases

This section shows the results for all cases. Following the approach of the previous section, we first present the consolidated mean results, before looking at the probability of a technology of having the lowest TCO/km. Figure 2 shows the mean TCO/km results for the years 2014, 2020, and 2025 for each of the combinations among our three vehicle classes and the three use cases. We also estimated the market share per case based on the market share per vehicle class and share of drivers per use case (cf. Table 2 and 3). Since we put our emphasis on the mean TCO/km differences for each TCO case rather than the comparison of the total mean TCO/km across cases, the TCO/km scale are not the same for each case. For the scaled view, please refer to Figure A.3.

Our model projects a cost decrease for BEV until 2020. After 2020, this cost decrease is projected to be weaker (in the short distance cases) or turn into an increase (in the medium and long distance cases). This is mainly due to the yearly battery price decrease, which is projected to be -8.39% until 2020 and -4.86% afterwards. In the medium and long distance cases, the lower decrease rate after 2020 cannot compensate for the increasing energy prices. These
energy prices are also the main reasons why the mean TCO/km of all vehicles are likely to be higher in 2025 than in 2014, except for BEV in the short distance cases and in the A/B, medium distance case, in which the battery price has a higher effect on the total TCO/km than in other cases. In general, ICEV and HEV are projected to have stronger cost increase than PHEV and BEV resulting in smaller cost discrepancies among the powertrain technologies in eight of the nine cases.

In the short distance cases, the results indicate that the mean TCO/km for PHEV and BEV are likely to remain higher than the mean TCO/km of ICEV and HEV. However, the cost gap converges strongly until 2025. The same applies to the medium distance cases except for the A/B class, where a PHEV can have a lower mean TCO/km than ICEV in 2025. For the long distance cases, BEV can become the cheapest technology in the A/B class in 2020. In the C/D and J classes, HEV is likely to be the technology with the lowest TCO/km followed by BEV. Different to the medium distance cases, PHEV has a higher mean TCO/km than BEV in each vehicle class of the long distance cases.

Due to the uncertainty of the input parameters however, the results vary across the 10,000 simulations. Figure 3 shows the distribution of all TCO/km outcomes for each TCO case. In all short distance cases, ICEV has the lowest mean and minimum value. But the range of ICEV outcomes includes all possible outcomes of HEV. In the medium distance cases, the results are highly overlapping. In the A/B class, HEV and PHEV have almost the same results regarding both the mean value and the distribution of outcomes. In the C/D and J class, HEV has the lowest mean TCO/km. However, its results are highly overlapping with the results of ICEV. In the long distance cases, the A/B class is likely to have BEV as the technology with the lowest TCO/km indicated by both the mean TCO/km and the distribution patterns. For the other classes, the results of at least two technologies are highly overlapping.
Since the distributed outcomes are highly overlapping, we added an analysis of the probability of having the lowest TCO/km for each technology in order to determine the most cost-efficient technology. For each vehicle class and driving distance combination, Figure 4 shows this probability for the years 2014, 2020, and 2025. For the short distance, ICEV is most likely to remain the most cost-efficient solution. For the medium distance, we calculated a 15% probability for PHEV to become the most cost-efficient solution in 2020 and a 44% probability in 2025 in the A/B class. For the C/D and J classes, the conventional powertrains will likely remain the most cost-efficient technologies. However, different from the short distance cases, HEV are more likely to be the most cost-efficient technology in 2025.

For the long distance cases, BEV are likely to have the lowest TCO/km. In 2025, BEV have the highest probability in the A/B (with 82%), and the second highest probability in the C/D (with 39%) and J class (with 41%). With 47%, BEV has the highest probability of becoming the most cost-efficient technology in the A/B class already in 2020. Interestingly, the TCO/km of PHEV
is not likely to be the lowest in any combination for this distance. As of 2020, the main TCO competition takes place between BEV and HEV.

Based on the results, Figure 5 shows a clustered view on the technologies with the lowest TCO/km in 2025. We attributed a case to a certain technology if this technology has the lowest mean TCO/km, a lower outcome distribution than the other technologies (Figure 3), and more than 10% higher probability than the next technology of having the lowest TCO/km (Figure 4). The cluster overview shows that there is no uniform technology solution for the whole market. ICEV is likely to remain the most economic technology for short distance drivers. For the mid distance cases, HEV and ICEV could both become the cheapest technology for the C/D and J segment, whereas HEV and PHEV could be cheapest in the A/B segment. For the long distance cases, BEV is likely to become the cheapest solution for the A/B segment indicating the segment where EV is likely to be most cost-efficient compared to ICEV. In the C/D and J class, both HEV and BEV have around or over 40% probability of having the lowest TCO/km.

Figure 4. Probability of being the technology with the lowest TCO/km.
From an EV perspective, the cluster views shows that PHEV and BEV have the highest chance of becoming the cheapest technology in the three long distance cases and the medium distance, A/B case. These four cases represent a current market share of 20% in Germany.

Figure 5. Clusters of most economic technology.

3.3. Sensitivity analysis

To show the maximum impact each parameter can cause on the mean TCO/km, we present the results of 2025 because the impact of parameters used for projections increases with the applied time period. The ranking and relative importance of the input parameters barely deviates among vehicle classes. Hence, only the results for the A/B class, which is the class where electric powertrains are most competitive in terms of TCO/km (Figs. 3 and 4), are shown. In order to illustrate the extreme cases, Figure 6 presents the sensitivity analysis for the short and long distance cases for the two opposing technologies ICEV, with no electric propulsion, and BEV, with solely electric propulsion. Each case has a graph with the input parameters ranked according to their impact on the results. This impact is presented as the variance the respective parameter can cause. To determine the relative importance of one parameter, we compared the variance one input parameter can cause divided by the total variance caused by all inputs. For ICEV-SI for instance, the relative importance of gasoline price development increases with the driving distance. This is illustrated by a share of total range of mean increase from 7% to 13%.

The TCO/km of vehicles with a conventional powertrain is most sensitive to operating cost parameters except for the vehicle purchase price, whereas the TCO/km of vehicles with electric
powertrains is most sensitive to the vehicle glider, and battery capital cost parameters and their projections. The more electrified the vehicle is, the more important are parameters related to the battery. In general, the top five parameters can explain a high portion of the variance of the outcomes. However, whereas the top five parameters can explain around 80% of the variance of ICEV-SI, they only explain around 50% of the variance of BEV.

Figure 6. Sensitivity analysis for selected cases in 2025.

4. Discussion

We aimed to find out how the TCO of vehicles with different powertrain technologies compares to each other today and in the future. To do this, we calculated the TCO/km for different vehicle class and driving distance combinations. Using Monte Carlo simulations, we identified both the statistical probability of the powertrain technology with the lowest TCO/km and the input parameters with the highest effect on the TCO/km. The results indicate that the comparative

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14 This is due to the fact that our model incorporated more uncertain parameters for vehicles with electric powertrains than for vehicles with conventional powertrains.
cost efficiency of EV highly depends on the annual driving distance and the vehicle class. In some TCO cases, such as the short distance ones, ICEV are likely to remain the most cost-efficient technology until 2025, whereas in other cases, such as the long distance ones, EV can be more cost-efficient than ICEV in 2025. This is mainly due to the lower operating cost per km of EV compared to conventional vehicles. In contrast, the capital cost remains higher for EV than conventional vehicles across all cases. A longer driving distance leads to a higher weighting of the operating cost in the total TCO calculation and thus increases the comparative cost efficiency of EV. Consistently, smaller vehicles with relatively lower capital cost\textsuperscript{15} also lead to a higher weighting of operating cost in the total TCO calculation and thus increases the comparative cost efficiency of EV. However, the comparative cost efficiency among different technologies is not certain. Our Monte Carlo simulations show highly overlapping distributions of possible TCO outcomes among powertrain technologies due to the sensitivity of the results to uncertain parameters such as fuel, electricity, vehicle glider, and battery cost development. Hence, there is potential for policy measures to influence the capital and operating costs. With federal tax credits for instance (Tseng et al., 2013), which is currently not given in Germany, the capital cost would be reduced. As an example, since the TCO/km of HEV and ICEV are already close today, any federal tax credit of over EUR 2,700 would make an A/B or C/D class HEV more cost-efficient than a comparable ICEV, even in the short distance cases\textsuperscript{16}. In addition, we only assumed a natural fuel price increase based on expert estimations. Policy induced tax measures decreasing the relative cost of electricity to fuel price could increase the operating cost efficiency of EV. Hence, we see opportunities for EV to become the most cost-efficient solution in the near future.

Our findings extend the understanding of the cost efficiency of EV compared to conventional vehicles by providing a more comprehensive and at the same time case-specific view on the vehicle market compared to past studies (e.g. Bickert and Kuckshinrichs, 2011; Thiel et al., 2010). In addition, our probabilistic results provide the basis for a more cautious interpretation of TCO in contrast to deterministic results of past studies (e.g. Lin et al., 2013). By showing

\textsuperscript{15}The marginal battery cost increases with the size of the battery. Therefore, larger EV have disproportionately higher capital cost.

\textsuperscript{16}For the A/B and C/D class vehicles in the short distance cases, the TCO/km discrepancy between ICEV and HEV purchased in 2014 is approximately EUR cent 4 and 6, respectively, which is equal to a total ownership cost discrepancy of EUR 1,800 and 2,700, respectively.
that the comparative cost efficiency among technologies is uncertain, we point out the potential influence and thus the importance of policy measures, which we discuss in the following section along three matters. First, we suggest policy measures which can leverage the case-specific differences in comparative cost efficiency of powertrain technologies to promote EV. Second, we present some thoughts on the infrastructure requirements to obviate the seeming contradiction between the high EV cost efficiency in long distances cases and the limited EV range. Third, we discuss policy measures to reduce battery cost, which has a decisive impact on the future comparative cost efficiency of EV.

First, to leverage the case-specific cost efficiency differences, we suggest policy measures which facilitate the consumers’ engagement in a TCO evaluation for their respective case. Such a TCO evaluation is currently not convenient for the consumer to conduct but can uncover the individual cost efficiency of EV (Contestabile et al., 2011). There are online calculation tools available to approximate the TCO of EV compared to conventional vehicles based on driving characteristics and vehicle class preferences of the consumer (e.g. U.S. Department of Energy, 2014; UC Davis, 2014). These tools are using different methodological approaches and, similar to existing literature, all have different scopes regarding cost elements, vehicle types, or regions. The difference of the tools might make it difficult for policy makers to promote and for consumers to recognize a best practice. Hence, the consolidation of the currently fragmented platforms to one standardized platform could enable targeted promotions by policy makers and therefore increase the TCO awareness. As our results show that the TCO of EV will become more competitive compared to conventional vehicles in the future, the probability of changing the high cost perception of EV with such a promoted tool could also increase. In addition, cost labels can signal the comparative TCO among technologies. Such a label can nudge customers towards cost-efficient decisions as evidenced in the EnergyGuide label, which shows the estimated annual operating costs and is mandatory for the major household devices in the US (Newell & Siikamäki, 2013). A label showing the TCO could alleviate the higher cost perception of EV. However, such a label should be differentiated by annual driving distances showing the different TCO ranges for at least three different distance ranges. Thereby, customers with high annual driving distances can easily realize the operating cost advantages of EV. Similar to the introduction of the EnergyGuide label, such a TCO label should be induced by policy makers because the industry has little interest in creating cost competition for their own conventional vehicles.
Another implication from the case-specific cost efficiency differences is that the support of a market shift toward smaller vehicles per se would be an indirect way to promote EV. Due to the higher comparative cost efficiency of EV in the A/B than in the C/D or J class, customers should be more inclined to buy an EV in the small vehicle class. Japan is an example of showing the success of a policy induced vehicle class shift. The country introduced the Kei car regulation to provide various incentives (e.g. tax abatement, insurance support, and dedicated parking area) to owners of small vehicles independent of the powertrain technology. This regulation was one main reason why Japan, with 57% of its fleet being categorized as small cars, has a significantly higher share of A/B vehicles than other industrial countries (Road Transport Bureau, 2013). Together with cost labels, which would make the cost advantages of small EV obvious to customers, such a general transition toward small vehicles would indirectly increase the attractiveness of EV compared to ICEV.

Second, a longer annual driving distance might be contradictory to the limited range of EV. Although there are only a few occasions in a year in which a typical German passenger car driver drives more than the maximum possible BEV range of 150 to 200 km at a stretch (Statista, 2014c), the significantly lower range of EV compared to ICEV still constitutes a psychological barrier because customers value the possibility of driving a long range (Lieven, Mühlmeier, Henkel, & Waller, 2011). Hence, an extension of the current charging infrastructure would improve the boundary condition for the EV transition in the long distance cases, in which EV have the highest comparative cost efficiency. Currently, policy initiatives are still focused on the charging infrastructure within cities. The Munich municipal utility (SWM) for instance installed approximately 20 charging stations in the inner city. Considering a possible mass transition towards EV however, the range problem is less relevant for the inner city travels than for long distance travels between cities. It is these few times in a year, when people want to conduct long distance travel to other cities, which make range a barrier to EV purchase (Lieven et al., 2011). Hence, a long term EV transition also requires charging opportunities between cities. Since many policy initiatives are currently driven by regional communes, charging stations across communes require a broader collaboration among communal policy makers. There is a natural incentive for the communes, which often owns the regional electricity providers, to provide charging stations in order to increase electricity demand. This incentive is also given for a supraregional charging network. Given an acceptable business case, a joint investment commitment by a critical amount of communes and a supraregional governing body
for the construction and administration could be first steps to initiate the charging network. In a broader context, policy makers can initiate industry platforms to involve the industry in the infrastructure development. Such platforms (e.g. National Platform for Electric Mobility) have successfully catalyzed R&D and business collaborations in the field of EV in the past (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2011). However, although the direct current fast charging technology allows EV batteries to fully recharge in less than 60 minutes, charging time is still significantly higher than refueling time. Hence, the facilitation of the charging infrastructure needs to be supported with innovative solutions to alleviate the high charging time required. One exemplary solution could be a battery swap station, at which depleted batteries can be exchanged for recharged ones in the middle of long trips (Mak, Rong, & Shen, 2013). Because battery swap requires new business models (e.g. battery leasing), which might not suit every consumer, the combined provision of charging and swapping at one location might be appropriate. Since swapped batteries can also serve as electricity storage devices connected to the power grid (Nurre, Bent, Pan, & Sharkey, 2014), electricity providers might be interested in offering both solutions.

Third, policy measures targeted at the battery manufacturing cost can have a high impact on vehicle TCO. Our sensitivity analysis shows that the battery cost development has the second highest impact on the TCO results of EV next to the vehicle glider cost. Together with existing findings indicating that the cost of Lithium-ion batteries are most uncertain among existing storage technologies (Battke, Schmidt, Grosspietsch, & Hoffmann, 2013), we conclude that future measures to reduce the battery cost be it from industry or policy makers have the potential to highly influence the comparative cost efficiency of EV. Some approaches to reduce these manufacturing costs mentioned in our interviews are the increase of economies of scale, technical improvement of the battery cells leading to lower material costs (e.g. by increasing the depth of discharge), and improvement of the manufacturing process. Regarding economies of scale, policy makers could directly support EV market diffusion through the purchase of EV for public fleets (e.g. government or police fleet) and indirect facilitate EV purchase through subsidies such as tax credits (Tseng et al., 2013). Regarding R&D, recent research indicate that the anticipated battery cost reductions necessary to achieve ambitious national EV targets might not be achieved with the current amount of public R&D funding (Baker, Chon, & Keisler, 2010; Catenacci, Verdolini, Bosetti, & Fiorese, 2013; Cluzel & Douglas, 2012). Despite having higher EV sales and stock targets than China, EU countries together granted less public R&D funding
than China in the past 2 years (IEA, 2013). This indicates that increased R&D funding within the EU, which is the headquarters for many leading OEM (e.g. BMW, Opel) and system integrators (e.g. Bosch, Continental), might be an appropriate way to further decrease the battery cost. In addition to the amount of spending, more international, joint funding programs could further contribute to cost decrease. Whereas many national funding programs have been initiated for decades\textsuperscript{17}, supranational R&D funding programs have just been initiated in the recent six years. The European Green Vehicle Initiative, established in 2009, is one example of what we see as the possible way to leverage the synergies from all the national research. Although such international R&D collaborations imply challenges (e.g. aligned targets, concerted actions, joint institutions), which are easier to overcome within the EU than on a global scale, they might be worth the effort because past studies have shown their positive impact on technical innovation (e.g. Lewis, 2014). These ideas are in line with recent research indicating that the interplay between market support and R&D funding has proven to be successful for the market diffusion of a new technology (Bointner, 2014).

Regarding the generalizability of our study, the TCO/km results are subject to the country specifics (e.g. taxes, electricity prices, fuel prices, insurances). For instance, in countries such as the US, where the fuel price is lower than in Germany, the comparative cost efficiency of EV would be in general lower due to the smaller share of the operating cost in the TCO. In contrast, in UK or the Netherlands, where the electricity price is significantly lower and the fuel price is higher (European Commission, 2014a; Statista, 2014a), the comparative cost efficiency of EV would be higher. Hence, the interpretation of when and in which case EV become more cost-efficient than conventional vehicles may vary across countries. Our policy implications however, are drawn from our general observations regarding the change of cost efficiency across the TCO cases and the sensitivity of the results to certain parameters. These implications are related to the general increase of the comparative cost efficiency of EV and can thus be relevant for other countries beside Germany.

From a broader perspective, we want to acknowledge two limitations conditioned by our focus on the detailed as well as market-wide costs assessment for the first vehicle owner. First, this paper does not consider environmental and societal costs, which impact the society and national

\textsuperscript{17} For instance, the USA already supported electric vehicle research with The Electric Vehicle Research, Development, and Demonstration Act of 1976.
economy, but not directly the TCO of the individual vehicle owner\(^\text{18}\). This kind of broader impact might very well influence the purchase decision of a consumer, which brings us to our second limitation. Consumers do not make their purchase decisions exclusively based on costs. Studies using consumer choice and agent-based models have shown the importance of additional consumer utilities and put individual consumer characteristics in correlation with vehicle characteristics and context factors to generate market predictions (e.g. Baha M Al-Alawi and Bradley, 2013; Axsen and Kurani, 2013; Lin and Greene, 2010). Our data also confirm that the cost perspective is not sufficient to predict the market. Our outcomes indicate that HEV is almost as cost-efficient as ICEV already today, especially in the long distance cases. In 2013 however, there were only 26,348 HEV sold in Germany representing only approximately 0.9% of the total German passenger car market (Kraftfahrt-Bundesamt, 2014). Hence we see our study as a detailed way to understand one important decision criterion of the consumer, which needs to be complemented with other decision criteria as implemented in agent-based or consumer choice models.

5. Conclusion and policy implications

This study simulated the present and future TCO/km of vehicles with electric and conventional powertrain technologies across three vehicle classes and three use cases. The results indicate that EV will increase their cost efficiency relative to conventional vehicles across all cases. However, our Monte Carlo simulations show that the statistical distributions of the possible outcomes overlap across technologies. Hence, there is no clear distinction of the most cost-efficient technology. Our probability analyses show that the comparative cost efficiency of EV is strongly determined by the driving distance and vehicle class. Whereas conventional vehicles have a high probability to remain most cost-efficient in the short distance cases, EV have a good probability to become most cost-efficient in the small vehicle class in the medium distance cases and in all vehicle classes in the long distance cases.

The results imply two main insights. They show that the comparative cost efficiency of EV highly depends on the vehicle class and annual driving distance of the consumer. Moreover, the future comparative cost efficiency is still uncertain and can hence be influenced by policy

\(^{18}\) We assume that the current environmental and societal costs that are affecting the consumer’s TCO are reflected in in the taxes of the vehicle, gasoline, diesel, and electricity.
measures. Based on these insights, we derived three main policy implications. First, customers should be educated about the TCO fitting to their respective vehicle preference and driving distance. Otherwise, customers might intuitively consider only the capital cost, which is higher for EV than for conventional vehicles in all cases (Offer et al., 2011). Cost labels signaling the cost-efficiency of vehicles per driving distance category and a recognized online TCO calculation platform are two possible measures of customer education. Also the support of a market shift toward smaller vehicles per se would promote EV because they are more cost-efficient in the smaller than larger vehicle classes. Second, the charging infrastructure between cities needs to be developed to obviate the seeming contraction between the positive effects on the comparative cost efficiency of EV of increased driving distance and the limited driving range of EV compared to conventional cars. For this, the currently regional infrastructure initiatives of communities could be organized into supraregional initiatives to increase the charging network density and introduce innovative ways of energy provision. Third, increased public R&D spending and more international funding programs could support the battery price decrease, which would have a high impact of the TCO.

For further research in the field of EV, we propose scholars to include probabilistic parameters in techno-economic analyses to avoid the potentially misleading impression that the results are clear and determined. In addition, we also propose a higher emphasis on vehicle classes and use cases in future analyses because the final outcomes are highly sensitive to these parameters. This can further contribute to our understanding of the market segments where EV might become cost-efficient. At a broader scope, we acknowledge that our implications are solely drawn from a TCO perspective, which is just one out of several factors influencing the buying decision of the customer and hence the market diffusion of EV (Eppstein, Grover, Marshall, & Rizzo, 2011). The relative impact of each decision factor on the market diffusion might be highly related to the country-specific context (e.g. regulations, tax incentives, share of fleet vehicles). Therefore, future studies could consider other decision factors valued by customers such as vehicle model options, range, charging time and opportunity, or environmental performance and the context factors of a country to derive the attractiveness of EV compared to conventional vehicles (Bunce, Harris, & Burgess, 2014; Driscoll, Lyons, Mariuzzo, & Tol, 2013; Hoen & Koetse, 2014).
Figure A.1 Capital cost calculation concept.
Operating cost calculation concept.

**Figure A.2.** Operating cost calculation concept.

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>A/B</th>
<th>C/D</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driving distance</strong></td>
<td><strong>ct. €/km</strong></td>
<td><strong>ct. €/km</strong></td>
<td><strong>ct. €/km</strong></td>
</tr>
<tr>
<td><strong>Short</strong></td>
<td>11%</td>
<td>18%</td>
<td>7%</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>10%</td>
<td>16%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Long</strong></td>
<td>3%</td>
<td>5%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Share of new vehicles sold; all nine cases cover approx. 78% of the total new vehicles sold market.

**Figure A.3.** TC/km projection until 2025 scaled.
Table A.1. Other key capital cost parameters in 2014.

<table>
<thead>
<tr>
<th>Parameter Category</th>
<th>Cost in EUR</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warranty</td>
<td>5% of battery cells cost</td>
<td>(Douglas &amp; Stewart, 2011; Redelbach, Klötze, &amp; Friedrich, 2012; Santini et al., 2010)</td>
</tr>
<tr>
<td>Pack integration</td>
<td>290</td>
<td></td>
</tr>
<tr>
<td>Thermal Management</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Glider A/B, C/D, J</td>
<td>5,111/ 9,468/ 10,700</td>
<td></td>
</tr>
<tr>
<td>Engine and Transmission cost per kW (not for BEV)</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>E-motor and motor controller cost per kW (not for ICEV)</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Other positions (e.g. fuel tank, ICE aftertreatment)</td>
<td>500 – 2000</td>
<td></td>
</tr>
</tbody>
</table>

Table A.2. Assumptions regarding distribution of parameters

<table>
<thead>
<tr>
<th>Distributions</th>
<th>Parameter-category</th>
<th>Input parameter</th>
<th>Rationale for the type of distribution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAR-SON</td>
<td>Capital cost in 2014</td>
<td>Vehicle price (only ICEV) in 2014</td>
<td>The distributions of these parameters are determined by the factual empirical distribution in the market. The PEARSON distribution allows us to set the distribution according to the market data.</td>
<td>(Kraftfahrt-Bundesamt, 2013b)</td>
</tr>
<tr>
<td></td>
<td>Operating cost in 2014</td>
<td>Vehicle energy consumption in 2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BETA</td>
<td>Capital cost in 2014</td>
<td>Other cost positions (e.g. engine and transmission, electric motor system, on board battery charger, and battery cell)</td>
<td>The existing sources provide deterministic reference costs with the indication (but no data) that these costs vary across vehicles. We also know that these costs cannot be below zero. With the BETA distribution, we could normally distribute the data (since there are no other assumptions) and set the value boundaries above zero.</td>
<td>(Cluzel &amp; Douglas, 2012; Deutsche Automobil Treuhand GmbH (DAT), 2012)</td>
</tr>
<tr>
<td>PERT</td>
<td>Capital cost projection</td>
<td>Yearly change in battery price 2020 vs. 2014</td>
<td>Various other institutions or experts have projected the future development of these parameters. Hence, we could derive the maximum, average, and minimum values of these projections. With the PERT distribution, we could use these values as the distribution boundaries.</td>
<td>(Cluzel &amp; Douglas, 2012; Plötz et al., 2013; Santini et al., 2010)</td>
</tr>
<tr>
<td></td>
<td>Operating cost projection</td>
<td>Yearly change in gasoline price 2025 vs. 2020</td>
<td></td>
<td>(Mineralölwirtschaftsverband e. V., 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yearly change in diesel price</td>
<td></td>
<td>(BDEW, 2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yearly change in electricity price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Operating cost projection</td>
<td>Yearly improvement in fuel economy</td>
<td>The existing source provides data to make one deterministic projection, but not a distribution of projections. Hence, we used the normal distribution as the most common approach to approximate unknown distributions.</td>
<td>(Plötz et al., 2013)</td>
</tr>
<tr>
<td>Parameters</td>
<td>N</td>
<td>Mean</td>
<td>St. dev.</td>
<td>1)</td>
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<td>------------------------</td>
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</tr>
<tr>
<td>1) Gasoline price</td>
<td>16</td>
<td>123</td>
<td>25.1</td>
<td>1</td>
</tr>
<tr>
<td>2) Diesel price</td>
<td>16</td>
<td>105</td>
<td>28.1</td>
<td>0.994</td>
</tr>
<tr>
<td>3) Electricity price</td>
<td>16</td>
<td>20</td>
<td>4.4</td>
<td>0.896</td>
</tr>
<tr>
<td>4) ICEV purchase price</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5) Vehicle glider price</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6) Maintenance &amp; repair</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7) Insurance costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table A.4. Range of absolute TCO results in 2014 (in EUR)

<table>
<thead>
<tr>
<th>Drivetrain</th>
<th>Cost position</th>
<th>A/B</th>
<th>C/D</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHEV</td>
<td>Capital cost</td>
<td>17.242</td>
<td>23.361</td>
<td>34.118</td>
</tr>
<tr>
<td>BEV</td>
<td>Capital cost</td>
<td>20.319</td>
<td>27.410</td>
<td>38.797</td>
</tr>
</tbody>
</table>

Notes: The capital cost and resale price are shown as values at the current point of time without consideration of future interest rates. Thereby, the reader can compare them to existing list prices. For the TCO/km simulation, we considered the sum of the annuity including the interest rates.
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The impact of demand-pull and technology-push policies on firms’ knowledge search

Jörn Hoppmann*, Geng Wu, Jillian Hughes

ETH Zurich, Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56/58, Zurich, CH-8092, Switzerland

* Corresponding author contact details:

jhopmann@ethz.ch

Phone: +41 44 632 82 03
Abstract

How firms search for knowledge critically affects their innovative and financial performance. Previous studies provide important insights into the antecedents of firm knowledge search. Yet, we currently still know little about how the search activities of firms are affected by public policies. Against this background, this study examines the impact of demand-pull and technology-push policies on the scope and distance of firms’ knowledge search. We hypothesize that in times of strong policy support in a technological field, firms will be confronted with large amounts of new knowledge, to which they react by narrowing their attention and search scope. Moreover, we argue that technology-push policies will enhance and demand-pull policies reduce search distance, and that the influence of policies on search scope will be moderated by the breadth of the firm’s existing knowledge base. We test and find broad support for our hypotheses based on an analysis of a global sample of 245 publicly listed firms in the solar photovoltaics industry from 1988 to 2012. Our findings suggest that, while innovation policies play an important role for knowledge generation and industry emergence, they may have unintended, adverse effects on firm knowledge search. We discuss the implications of these findings for the literature on organizational search, innovation policies, and technology life-cycles.

Keywords: Search, knowledge, attention, innovation policy, demand-pull, technology-push, solar photovoltaics
1. Introduction

The ability to develop new products and processes is of critical importance for firm performance and longer-term survival (Damanpour, 1991; Mitchell & Singh, 1993; Smith, Collins, & Clark, 2005). The literature suggests that developing such innovations requires firms to engage in a process of “search” to identify, recombine and integrate knowledge (Dahlander, O'Mahony, & Gann, 2014; Katila & Ahuja, 2002; Laursen & Salter, 2006). Two important parameters in this search process are the search scope and search distance chosen by the firm. Search scope (narrow vs. broad) describes the number of knowledge sources a firm attends to when developing new technologies (Katila & Ahuja, 2002). Search distance (local vs. distant), in turn, is the extent to which firms search for knowledge far from their existing knowledge base (e.g., Helfat, 1994a; Piezunka & Dahlander, 2015).

It has been shown that firms tend to search for new knowledge narrowly and locally, which primarily results in incremental innovations (Ahuja & Katila, 2004; Benner & Tushman, 2002; Nerkar & Paruchuri, 2005; e.g., Stuart & Podolny, 1996). To develop more radical innovations, firms need to engage in the search for knowledge more broadly and distant from their existing knowledge base (Afuah & Tucci, 2012; Fleming, 2001; Fleming & Sorenson, 2004; Laursen, 2012; Leiponen & Helfat, 2010; Singh & Fleming, 2010). Given these important ramifications of different search processes for innovative outcomes, scholars have started to take a more detailed look at the antecedents of firm knowledge search. For example, research has shown that distant search may be triggered by employee turnover, alliances, or mergers and acquisitions (Rosenkopf & Almeida, 2003). So far, however, we know little about how a firm’s knowledge search may be influenced by public innovation policies, i.e. formal institutions implemented to foster innovation in an industry.

The broader literature on technological change suggests two generic ways through which policies may affect innovation: technology-push and demand-pull (Dosi, 1982; Mowery & Rosenberg, 1979; Rosenberg, 1969, 1974). Technology-push policies comprise those policy measures that aim to increase the supply of technologies by directly fostering advances in science and technology, e.g. through public R&D funding (Nemet, 2009). Demand-pull policies include those policy measures that aim to stimulate technological innovation by altering market conditions, e.g. through direct demand incentives or shifts in factor prices (Edler & Georghiou, 2007).
In this paper, we argue that besides stimulating innovation, technology-push and demand-pull policies also affect the scope and distance of firms’ knowledge search. First, with regard to search scope, we reason that by raising the amount of knowledge available in a technological field (e.g., Peters, Griesshaber, Schneider, & Hoffmann, 2012), both technology-push and demand-pull policies reduce firms’ search scope. A broader availability of knowledge increases the possibility of knowledge recombination, which provides them with an incentive to search more broadly (Fleming, 2001; Hargadon & Sutton, 1997). Still, we posit that in practice firms tend to reduce their search scope when facing rapidly increasing policy-induced knowledge since the latter allows firms to find solutions to specific problems more quickly, results in information overload, and raises the opportunity costs of broad search (Huber & Daft, 1987; Laursen, 2012; Piezunka & Dahlander, 2015).

Second, with regard to search distance we argue that technology-push policies enhance, while demand-pull policies reduce firm’s distance in knowledge search. Extant studies suggest that in contrast to technology-push, changes in demand trigger innovation primarily within established technological trajectories (Freeman, 1996; Mowery & Rosenberg, 1979). More recent work points out that the impact of technology-push policies may be limited due to “crowding out” (Czarnitzki & Lopes-Bento, 2013; David, Hall, & Toole, 2000; Görg & Strobl, 2007) and that demand-pull policies may also trigger distant search (Hoppmann, Peters, Schneider, & Hoffmann, 2013). Still, we contend that demand-pull policies induce firms to primarily invest in local search, while technology-push policies trigger more distant search activities since the incremental nature of changes in demand is less suited to foster radical deviations from the status quo (Nemet, 2009).

To test our hypotheses, we draw on panel data for a global sample of 245 firms in the global solar photovoltaic (PV) industry from 1988 to 2012. The PV industry is particularly well-suited for testing the relationship between policy and firm search as in this period the industry was strongly dependent on policy support (Branker, Pathak, & Pearce, 2011; Peters et al., 2012). Besides testing how public innovation policies affect search scope and distance, we investigated how the existing knowledge base of firms moderates the relationship between public policies and firm search.

We find that a higher prevalence of both technology-push and demand-pull policies is associated with a narrower search scope. Moreover, in line with our expectations, technology-
push policies enhance and demand-pull policies reduce a firm’s distance of knowledge search. A broader existing knowledge base reduces the negative effect of technology-push policies on search scope but also enhances the negative effect of demand-pull policies.

Our study contributes to the literature on organizational search, innovation policy, and technology life-cycles. Previous work on organizational search has largely ignored the impact that institutions exert on firm’s search for knowledge (Garriga, von Krogh, & Spaeth, 2013; Laursen, 2012). We show that public policies may decisively influence both the scope and distance of search. Similar to recent findings in the work on crowdsourcing (Piezunka & Dahlander, 2015), we show that incentivizing the generation of large amounts of external knowledge reduces the scope of firms’ knowledge search. In contrast to findings in crowdsourcing, however, we show that the driver behind external knowledge generation can lie at the industrial, rather than the firm level, and that there are ways to stimulate knowledge generation that do not compromise firms’ search distance. Our study also contributes to the literature on innovation policy. While previous work has provided anecdotal evidence of a differential effect of technology-push and demand-pull policies on innovation, to our knowledge we provide the first empirical tests of how search scope and distance are influenced by the two types of policies, allowing to draw conclusions on their influence on radical and incremental innovation. Finally, our study also makes contributions to the literature on technology life-cycles. We provide quantitative evidence that the relative importance of technology-push vs. demand-pull over the course of technology life-cycles may contribute to the emergence of technological paradigms and increasing rates of incremental innovation among firms.

The remainder of the paper is structured as follows: We first introduce the conceptual background of firm search based on which we developed our hypotheses. We then present our methodology and results. The paper ends with a discussion of the main implications for the literature and practitioners, and directions for future research.

2. Theory and hypotheses

One of the main tenets of organizational research in the tradition of the Carnegie School is that organizations are limited in their ability to perceive, retrieve and process knowledge (Cyert & March, 1963; Simon, 1982; Simon, 1991). Rather than optimizing based on complete information, it has been argued that firms engage in a process of search that often is of a local,
path-dependent nature (Cyert & March, 1963; Gavetti & Levinthal, 2000). Since the nature of search determines which information organizations consider when taking decisions, understanding the process of search is critical to understanding organizational problem solving and learning (Huber, 1991).

While in the original literature of the Carnegie School the concept of search was used to better understand organizational decision making and behavior more broadly, in recent years much research has applied the concept to understand how firms develop technological innovations. It has been argued that new products and services are the result of firms recombining knowledge from different sources and technological domains (Fleming, 2001; Hargadon & Sutton, 1997; Nelson & Winter, 1982; Von Hippel, 2007). Where the knowledge eventually integrated into a product comes from then depends on the search process applied by those developing the product within the firm (Katila & Ahuja, 2002; Rosenkopf & Nerkar, 2001). For example, it has been found that firms differ strongly with regard to their search scope and their search distance. Generally, firms’ knowledge search tends to be rather narrow and local (Ahuja & Katila, 2004; Benner & Tushman, 2002; Helfat, 1994b; Nerkar & Paruchuri, 2005; Piezunka & Dahlander, 2015; Stuart & Podolny, 1996). At the same time, however, a broader and more distant search for knowledge has been found to lead to more radical innovations and a higher rate of new product introduction (Afuah & Tucci, 2012; Dahlander et al., 2014; Laursen & Salter, 2006; Leiponen & Helfat, 2010; Li, Maggitti, Smith, Tesluk, & Katila, 2013; Rosenkopf & Nerkar, 2001; Singh & Fleming, 2010).

2.1 Antecedents of firm knowledge search

Given the importance of knowledge search for technological innovation and firm performance, recent work has started to shed more light on the antecedents of search. In this context, it has been shown that search is affected by factors residing both within organizations and their environment.

Empirical studies on firm-internal factors indicate that slack resources, external partnerships and alliances, employee mobility, firm size, and financial performance may all affect firm search. Firms with more slack resources, defined as “the pool of resources in an organization that is in excess of the minimum necessary to produce a given level of organizational output” (Nohria & Gulati, 1996), have been found to engage in broader, more distant knowledge search (Chen & Miller, 2007; Garriga et al., 2013; Troilo, De Luca, & Atuahene-Gima, 2014).
External partnerships, mergers and acquisitions, and employee mobility facilitate more distant search for new knowledge (Almeida & Kogut, 1999; Rosenkopf & Almeida, 2003; Song, Almeida, & Wu, 2003; Stuart & Podolny, 1996). Lastly, many of the antecedents above are influenced by firm size as larger firms tend to have more slack resources, more partnerships, or higher degree of diversification (Leiponen & Helfat, 2010).

Research on factors residing in the firm environment has focused on understanding how patterns in search processes are related to conditions in the industry, such as changes in markets or the rate of technological innovations. Studies indicate that higher industry dynamism and technological change tend to be associated with broader and more distant firm search (Jansen, Van Den Bosch, & Volberda, 2006; Leiponen & Helfat, 2010; Sidhu, Commandeur, & Volberda, 2007).

2.2 Demand-pull and technology-push policies and their effect on firm search

While the literature has investigated a number of antecedents of firm search, we currently know very little about how knowledge search in firms might be influenced by public policy (Lavie, Stettner, & Tushman, 2010). Generally, work in the field of technological change suggests that policies affecting firm innovation can be categorized into two broad categories: technology-push and demand-pull policies (Dosi, 1982; Kim & Dahlman, 1992; Mowery & Rosenberg, 1979; Nemet, 2009). Technology-push policies aim to raise the supply of new technologies by reducing the private cost of research and development (Nemet, 2009). Typical technology-push policy instruments include public R&D funding, tax reductions for R&D investments, incentives for cross-organizational knowledge exchange (e.g., in the form of policy-initiated industry platforms), and financial support for employee training and pilot projects (Nemet, 2009). Demand-pull policies aim to increase the private rents and reduce the uncertainty of future returns associated with innovations by stimulating the adoption of technologies on the demand-side (Edler & Georghiou, 2007). Demand-pull policies typically include standard-setting instruments (e.g., performance standards or the protection of intellectual property), federal procurement programs, and subsidies or tax credits for end consumers (Jaffe, Newell, & Stavins, 2002; Peters et al., 2012).

First studies have started to link technology-push and demand-pull policies with the literature on organizational learning and firm-level innovation (Hoppmann et al., 2013; Nemet, 2009). Currently, however, we lack systematic, quantitative evidence on how different forms of search
are related to these two types of policy interventions. Testing the effect of policy seems particularly important as public policies have been found to have profound impact on innovations in a large number of fields (Mazzucato, 2013; Salter & Martin, 2001). In the following, we therefore derive a number of hypotheses that relate technology-push and demand-pull policy with two characteristics of knowledge search, namely search scope and search distance. Acknowledging that firms differ in their initial knowledge base, we also develop hypotheses on how the effect of public policies might differ depending on the breadth of the firm’s existing knowledge base.

**Effect on search scope**

Search scope (narrow vs. broad) describes the number of knowledge sources a firm attends to when developing new technologies (Katila & Ahuja, 2002; Piezunka & Dahlander, 2015). By stimulating innovation activities, both technology-push and demand-pull policies raise the amount of knowledge available in a technological field (Freeman & Perez, 1988; Jaffe et al., 2002; Mowery & Rosenberg, 1979; Salter & Martin, 2001). Schmoch (2007), for example, shows that industries typically follow a so-called “double-boom cycle,” i.e., technology developments are first being driven by technology-push and later by demand-pull factors. Similarly, studying inventions in the renewable energy industry, Peters et al. (2012), Costantini et al. (2015), and Cantner et al. (2016) provide empirical evidence that patenting activities were driven by both technology-push and demand-pull policies. We argue that this increase in knowledge leads to a narrower search scope of firms in the industry affected by policy support.

At the first glance, the idea that an increase in knowledge due to public innovation policies leads to narrower firm search might sound counterintuitive since a larger knowledge stock raises the potential for knowledge recombination, thereby potentially creating an incentive for firms to broaden their search (Fleming, 2001; Gruber, MacMillan, & Thompson, 2008; Hargadon & Sutton, 1997). In fact, previous research has shown that firms draw heavily on publicly funded research as a source of new ideas (Narin, Hamilton, & Olivastro, 1997; Salter & Martin, 2001). The larger the amount of knowledge that is created by policy incentives, the larger the variety of valuable innovations that can potentially be created by drawing on and combining these knowledge elements (Katila & Ahuja, 2002; Klevorick, Levin, Nelson, & Winter, 1995). Therefore, one might expect firms to widen their search scope to take advantage
of the enhanced opportunity set that results from an environment characterized by growing knowledge (Leiponen & Helfat, 2010).

Still, there are several reasons why in practice firms might reduce, rather than broaden, their search scope when they face rapidly increasing amounts of knowledge. First, raising the number of potential solutions in the environment of the firm may lead to a situation where firms can find a solution to specific problems more quickly, hence reducing the need for broader search. According to the behavioral theory of the firm, organizations engage in “satisfying” rather than optimizing behavior (Cyert & March, 1963). As a result, they may be less interested in generating the best potential innovation from all possible knowledge combinations but rather in developing one that provides a satisfactory solution to the firm’s most immanent problems (Laursen, 2012). Enhancing the knowledge in a technological field through public policies may then reduce the time it takes for firms to find a satisfactory solution, similar to enhancing the number of winning balls in an urn from which firms draw potential solutions (Klevorick et al., 1995).

Second, innovation policies may narrow a firm’s attention. As has been pointed out in the attention-based view of the firm, organizations possess limited capacity to process information (March & Simon, 1958; Ocasio, 1997; Sullivan, 2010; Van Knippenberg, Dahlander, Haas, & George, 2015). Especially if the amount of knowledge in a firm’s environment becomes large—so-called “crowding” (Ocasio, 2011)—firms may be unable to attend to all available opportunities and may narrow their search to a specific subset (Huber & Daft, 1987). Recent research on crowdsourcing, for example, shows that when firms receive a larger number of suggestions, the resulting information overload forces them to engage in more severe filtering (Piezunka & Dahlander, 2015). The amount of attention a firm pays to individual solutions has been found to decrease with the amount of solutions it is confronted with (Hansen & Haas, 2001; Sullivan, 2010). By stimulating the generation of knowledge, public innovation policies may hence narrow, rather than broaden, firms’ search scope.

Third, innovation policies may raise the opportunity costs of search. As described above, a key objective of technology-push and demand-pull policies is to speed up innovation in a particular industry. Searching for and integrating a larger amount of knowledge, however, has been shown to take considerable amount of time and effort (Katila & Ahuja, 2002). An enhanced speed of innovation puts pressure on firms to bring products to the market more quickly and raises the
risk of “oversearching” (Laursen & Salter, 2006). Public innovation policy may thus force firms to reduce the scope of their search and focus on a smaller number of knowledge elements (Dahlander et al., 2014). Overall, therefore, there is good reason to believe that public innovation policies reduce the search scope of firms. Accordingly, we phrase our first two hypotheses:

**H1a:** The larger the funding for technology-push policies, the narrower a firm’s search scope.  

**H1b:** The larger the funding for demand-pull policies, the narrower a firm’s search scope.

**Effect on search distance**

Search distance describes the technological proximity of the knowledge that is integrated into a new product from the existing knowledge base of the firm (Helfat, 1994a; Piezunka & Dahlander, 2015; Stuart & Podolny, 1996). Distant search aims at integrating technological knowledge that resides outside the firm’s current technological focus and competence (Afuah & Tucci, 2012; Gruber, Harhoff, & Hoisl, 2013). In contrast, local search focuses on integrating technological knowledge close to the existing knowledge base, thereby usually leading to incremental innovations within existing technological trajectories (Rosenkopf & Nerkar, 2001).

There are some indications that demand-pull and technology-push policies have different effects on search distance. In the literature on technological change, technology-push policies are generally regarded as means of variety creation that are believed to spur technological innovation outside existing technological trajectories (Freeman, 1996; Freeman & Perez, 1988; Mowery & Rosenberg, 1979). For example, in the context of renewable energy, technology-push policies have been used to incentivize research in radically new technologies far from the market, such as tidal and wave power or nuclear fusion. One would expect that by fostering the emergence of new technological fields, technology-push policies might change the distance of search firms engage in. In particular, if new, promising fields emerge as a result of policy interventions, this should raise the likelihood of firms engaging in more distant search to look beyond the technologies in their portfolio and integrate knowledge from the newly emerging technologies (Köhler, Sofka, & Grimpe, 2012).

Two mechanisms, however, may dampen the positive effect of technology-push policies on search distance. First, especially if the technological knowledge generated through technology-push policies is technologically distant from the one already present in the firm, this may reduce
the likelihood that it is considered by the firm in its search process (Kotha, George, & Srikanth, 2013). In fact, previous research shows that knowledge originating in public research funding is often encoded in specific ways and removed from commercial applications, such that firms require specific capabilities to be able to identify, interpret, absorb, and exploit it (Link, Siegel, & Bozeman, 2007). Second, and closely related to the first point, studies on “crowding out” suggest that public research funding often shows strong overlaps with private research funding. This is because firms may try to influence the areas for which public research funding is available and may systematically enter research projects on technologies close to their existing portfolio (Czarnitzki & Lopes-Bento, 2013; David et al., 2000; Görg & Strobl, 2007). While the two previously described effects reduce the likelihood that technology-push policies exert a strong impact on firms, we would still expect the overall impact of technology-push policies on firms’ search distance to be positive.

In contrast to the findings on technology-push policies, research suggests that demand-pull policies serve as a selection mechanism that predominantly foster local search along existing technological trajectories (Freeman, 1996; Mowery & Rosenberg, 1979). Based on a study of patent activities in the California wind power industry, for example, Nemet (2009) proposes that demand-pull policies may lead firms to primarily exploit existing technologies and may even reduce explorative search for new technologies. This view is in line with the traditional literature on technological change which argues that demand-pull cannot explain the emergence of radical innovations (Dosi, 1982, 1988). Although it is acknowledged that changes in demand may trigger innovations, researchers claim that changes in the needs of consumers do not occur abruptly, such that market-oriented knowledge search is primarily associated with imitations or incremental improvements (Köhler et al., 2012; Lukas & Ferrell, 2000).

Recent research has started to question the view that demand-pull policies predominantly foster incremental innovation. Hoppmann et al. (2013), for example, argue that demand-pull policies influence firm innovation activities not only by signaling changes in user needs but, more importantly, by providing the firm with the necessary financial resources. By allowing firms to generate revenues and attracting investors to an industry, demand-pull policies raise the capital available to firms that can be used to finance distant search and the development of radical innovation (Hall & Lerner, 2009; Hoppmann et al., 2013). Still, while these studies suggest that at an absolute level demand-pull policies raise firms’ distant search, they also acknowledge that
relatively speaking, demand-pull tends to more strongly foster local search activities. We hence phrase our next two hypotheses:

**H2a:** The larger the funding for technology-push policies, the larger a firm’s search distance.

**H2b:** The larger the funding for demand-pull policies, the smaller a firm’s search distance.

**Moderating effect of the firm’s knowledge base on search scope**

While the previously mentioned hypotheses suggest an impact of technology-push and demand-pull policies on firm search, it seems likely that the effect of public innovation policies on search differs between firms with different characteristics. For example, firms differ in the breadth of their existing knowledge, defined as “the extent to which the firm’s knowledge repository contains distinct and multiple domains” (Zhou & Li, 2012: 1091). It seems possible that differences in the breadth of firms’ knowledge base moderate the impact of technology-push and demand-pull policies on search. In particular, we would expect the breadth of the knowledge base to affect the influence of innovation policies on a firm’s search scope for several reasons.

First, previous research demonstrates that a broader knowledge base facilitates the search for and integration of knowledge. The literature on absorptive capacity, for example, suggests that a firm’s ability to integrate new knowledge sources is tightly coupled to its existing knowledge base as existing knowledge facilitates the decoding and interpretation of new knowledge sources (Cohen & Levinthal, 1990; Katila & Ahuja, 2002; Zahra & George, 2002). As a result, existing knowledge may significantly speed up the process of search, hence reducing the opportunity costs of broader search (Zhou & Li, 2012). Second, closely connected to the larger absorptive capacity, we would expect firms with a broader knowledge base to be able to attend to a broader range of different sources at the same time. Since this reduces the threat of information overload, we expect firms with a broader existing knowledge base to be less likely to narrow their attention and reduce their search scope in response to public innovation policies (Ocasio, 2011). We therefore phrase our last two hypotheses:

**H3a:** The larger the breadth of the firm’s knowledge base, the less technology-push reduce a firm’s search scope.
3. Methods

To test our hypotheses, we drew on a unique set of panel data on 247 firms in the global solar photovoltaic (PV) industry from 1988 to 2012. These data were analyzed using negative binominal and fractional logit regression models. In the following, we provide more details on the research context, data collection, variables, and statistical methods.

3.1 Research setting

We assessed our hypotheses within the context of the global PV industry between 1988 and 2012. The PV industry offers a suitable empirical context for examining the effect of policies on knowledge search as in this time frame the industry was strongly dependent on policy support. Solar PV allows generating electricity from sunlight, thereby emitting much less CO2 than when drawing on conventional sources, such as coal, nuclear, or gas. Yet, up to 2012, PV technologies were not cost competitive with electricity generation from conventional sources, except in small niche applications (Branker et al., 2011). To foster the broader development and diffusion of environmentally benign PV technologies, policy makers therefore implemented comprehensive support programs, using both technology-push and demand-pull policies.

Technology-push support for PV was particularly important during the early years of the industry from the 1970s to the early 1990s. In response to the two oil price shocks in 1973 and 1979, governments in several countries significantly increased their public R&D funding for solar photovoltaic technologies, leading to a 16-percent annual increase in patent filings from 1974 to 1985 (Peters et al., 2012). Although particularly in the US first policy measures, such as tax credits, were implemented to also foster the diffusion of technologies, the PV market remained very small until the end of the 1980s, primarily because of the very high cost of PV-generated electricity.

In the 1990s, then, Japan and Germany introduced comprehensive demand-pull programs, namely the “Sunshine program”, “1,000-roofs-program” and the “100,000-roofs-program”, which led to a significant upsurge in the size of the market (Jäger-Waldau, 2007). The market growth increased even further when in the year 2000, Germany implemented its “Renewable
Energy Sources Act” which granted owners of PV panels a fixed price for selling their electricity that was significantly above market price. As a result of this new legislation annual demand-pull funding for PV in Germany strongly increased from less than 50 million USD in 1992 to about 10 billion USD in 2012 (Hoppmann, Huenteler, & Girod, 2014).

Other countries, especially in the EU, followed suit, leading to an increase in the global market for PV panels from 20 megawatt annually installed capacity in 1992 to 30 gigawatt in 2012—an average annual growth rate of 44 percent (EPIA, 2014). At the same time, the annual funding for technology-push policies first fell drastically in the mid-1980s to slowly recover in the 1990s. Since then, funding has increased only slightly by about 2 percent per year (IEA, 2015). Although as part of the financial crisis in 2009, several governments implemented special R&D programs for solar PV, in an increasing number of countries the amount of demand-pull funding significantly exceeded the one for technology-push in 2012.

Depending on their maturity, PV can be categorized into first-, second-, and third-generation technologies (Green, 2006). Crystalline silicon (c-Si) PV represents the first generation technology, which is most mature. Invented in the 1950s, the development of c-Si PV was supported by the integrated circuit industry, which had a long history of manufacturing and processing these materials (Bagnall & Boreland, 2008). Second-generation technologies, or thin-film technologies, are less material intensive due to thinner absorbing layers and more strongly automated manufacturing processes (Tyagi, Rahim, Rahim, Jeyraj, & Selvaraj, 2013). However, since the technology originates from the 1970s, the technology is less mature and conversion efficiencies are lower than for first-generation PV. Third-generation technologies are the least mature and least competitive, but could further reduce material use and increase efficiency (Tyagi et al., 2013). So far, none of the three PV technologies has emerged as a clear winner, inducing firms in the industry to search for new technological solutions within and across all three technologies.

3.2 Data collection

To analyze the relationship between public policy and knowledge search in the PV industry, we relied on multiple sources of data. In line with previous studies (e.g., Katila & Ahuja, 2002; Rosenkopf & Nerkar, 2001) we used patent citations to measure knowledge search. Patent citations are a good measure to retrospectively assess firm knowledge search because each patent represents the solution to a stated problem. As a result, analyzing the citations listed in
patents provides insights into the sources firms drew on when developing a specific invention, which allows drawing conclusions about the scope and distance of knowledge (Katila & Ahuja, 2002). Global PV patent data was extracted from the “Thomson Innovation” database using a previously developed search string (see Table A1 in the appendix) that combines international patent classification codes (IPC) related to PV with keywords that were applied to patents’ title and abstract. In total, we extracted 96,771 patents. For each patent, we removed the examiner citations as these citations are not added by the inventor and are hence not indicative of firm search (Alcacer & Gittelman, 2006). Previous research indicates that examiner citations often represent a large proportion of total citations and can hence significantly bias analyses (Jaffe, Fogarty, & Banks, 1998).

Data on technology-push and demand-pull policies was obtained from the International Energy Agency’s “Energy technology research and development” database (IEA, 2015) and the European Photovoltaic Association (EPIA, 2014) respectively. The former database contains data on public R&D investments in PV for 15 OECD countries since 1975 and covers 80 to 90 percent of global public R&D investments in recent years (Breyer, Birkner, Meiss, Goldschmidt, & Riede, 2013).

Moreover, we used Thomson Reuters EIKON to extract firm-level data on factors other than policies that previous research had found to influence knowledge search. For this purpose, from our patent database we extracted all names of publicly listed firms that had filed at least one patent in PV technologies. Using the firm name, we then extracted data on firm size, profitability (e.g. operating and gross profit), solvency (e.g. assets, cash, long-term debts) and R&D spending from EIKON. To obtain data on alliances, we manually screened the press database Factiva as well as the two leading industry magazines “Photon” and “PV magazine” for announcements of partnerships and joint ventures in PV. This effort resulted in the compilation of a database containing 2,672 alliances among 1,943 firms. Finally, we drew on Thomson Reuters EIKON, Zephyr and Mergerstat to gather data on mergers and acquisitions (M&A) in the PV industry. The M&A data was manually cleaned and consolidated into a single database that contains detailed information on 1,314 M&A deals in the PV industry.

The firm-level and policy data from the different data sources was manually matched with the patent data to yield a longitudinal panel data set for the years from 1988 to 2012. The final
database contains data on 247 publicly listed companies active in the PV industry over an average period of 9.2 years.

3.3 Variables and measures

Our hypotheses imply the assessment of two dependent variables, search scope and search distance, and three independent variables, technology-push policy funding, demand-pull policy funding, and the breadth of the firms’ knowledge base.

Dependent variables

In line with previous work, we measure search scope by counting the number of patent citations in a firms’ patents for a specific year (Katila & Ahuja, 2002). A high number of patent citations indicates a broader search, whereas a lower number of citations indicates narrower search.

To measure search distance, we constructed a variable that measures the euclidean distance between the existing patent portfolio of firm i and the citations contained in the firm’s patents in a specific year t using the following formula:

\[ d_{i,t} = \sqrt{\frac{\sum_{k=1}^{4} \left( \frac{\sum_{t=0}^{t} p_{t,k}}{\sum_{t=0}^{t} p_t} - \frac{c_{t,k}}{c_t} \right)^2}{\sqrt{2}}} \]

In this formula, t denotes the focal year and i the focal firm for which to calculate the search distance d. p describes the number of patents a firm has filed in a specific technology category k. c is the count of citations contained in the firm’s patents in a specific technology category k. The formula then calculates the share of patents a firm has filed in a specific technology category up to the year of interest and compares this ratio with the number of citations to patents in the same technology category relative to the total number of citations contained in the firm’s patents in the year. The division by \( \sqrt{2} \) in the formula is done to scale the distance values such that they take values between 0 and 1. For example, a firm which in a focal year has only patented in one technology category and whose patents in that year contain only citations to patents in that same category will have a search distance of 0 (i.e., the patent portfolio resembles exactly the portfolio of patent citations in year t). A firm which up to the focal year has patented in only one technology category but whose patents in that year contain only patents from a
different category will have a search distance of 1 (i.e., the patent portfolio shows no overlap with the portfolio of patent citations in year \( t \)).

The categorization of patents and cited patents into technological domains was done using a self-developed algorithm. By searching for specific key words (see Table A2 in the appendix) in the title and abstracts of all patents in our database, all patents held by the 247 firms in our sample were assigned to one of four technological domains: (1) crystalline silicon PV, (2) thin-film PV, (3) third generation PV and (4) generic PV technologies (e.g., inverters, racks, absorbers). The patents cited in these patents were categorized in a similar way. In contrast to the patents, which included only PV patents, however, when categorizing the citations we added a fifth category for all citations to patents outside the PV sector.

**Independent variables**

Technology-push policies were measured by the annual amount of R&D funding dedicated to PV technologies in a specific country. Using country-level data to measure the effect of technology-push policies on firm search is reasonable since previous work indicates that technology-push policies exert an effect on innovation and knowledge generation primarily within national boundaries (Peters et al., 2012).

Compared to funding for technology-push, data on demand-pull funding in the PV industry is not as easily available as there is a plethora of different instruments, such as feed-in tariffs, renewable portfolio standards, public procurement, and financing schemes that operate at different levels. Those governments that monitor and publish data generally calculate the amount of annual demand-pull funding by calculating the difference cost between the electricity generated from PV and the one of conventional sources and multiplying it with the total amount of electricity generated from those plants installed in the focal year. The assumption behind this measure is that, for PV plants to be installed in the first place, demand-pull policy incentives have to cover the gap between the cost of electricity from PV and the (lower) electricity cost of conventional technologies in the market. For example, if in the US in 2001 PV plants were installed that generate 885,000 MWh of electricity over their lifetime, the cost of electricity from these plants is 0.34 USD/kWh and the cost of electricity from conventional sources is 0.05 USD/kWh, the annual amount of demand-pull funding required to make investments in PV profitable is \((0.34-0.05)\times(885,000,000) = USD 256.56M\). Following this approach, to obtain measures for demand-pull funding, we calculated the annual difference costs of solar PV for
each of the countries and years in our sample based on country-specific investment costs and irradiation conditions (Branker et al., 2011). The values for the individual countries were then added up to yield a global, annual measure for demand-pull funding. This was done because previous research indicates that, in contrast to technology-push policies, demand-pull policies in a specific country have a global effect on knowledge generation (Peters et al., 2012).

As an alternative to measuring demand-pull funding based on difference costs, we used the annual market size in gigawatt since this measure has been used to operationalize demand-pull policies in previous studies (Dechezleprêtre & Glachant, 2014; Klaassen, Miketa, Larsen, & Sundqvist, 2005; Peters et al., 2012). This measure is highly correlated with the measure based on difference costs (Pearson correlation coefficient of 0.94) since for many years, the cost of electricity for PV has been considerably above wholesale electricity prices (Branker et al., 2011), such that the market for PV technology would have been negligible without demand-pull support.

Finally, firm knowledge breadth as a moderating variable, was measured as the number of technological domains within PV in which a firm held patents at the time of interest. To count the technological domains, we relied on the categorization of patents also used for our measure of search distance, without taking into account patents that did not fall into the realm of PV (category 5). Based on the categorization of patents, we then calculated the knowledge breadth for all firms over time by counting the number of domains a firm was active in, ranging from 0 (active in no PV domain) to 4 (active in all four PV domains).

Control variables

In our analysis, we control for a large number of factors other than public innovation policy and knowledge breadth, which in previous research have been identified to influence firms’ knowledge search. Extant studies suggest that, although the direction of the effect is still controversial, financial performance can influence firm search behavior. While some scholars argue that strong financial performance leads to broad and distant search, other scholars argue that strong performance is likely to encourage managers to stay on course and hence exerts a negative effect on search scope and distance (Katila, 2002). In line with previous work, we measure financial performance by including firm’s return on assets.
A firm’s slack resources have been found to positively affect broad and distant search (Chen & Miller, 2007; Garriga et al., 2013; Troilo et al., 2014). In this study, we controlled for a firm’s slack resources by including the firm’s ratio between cash and long-term debt.

R&D intensity, i.e. a firm’s R&D expenses divided by sales, is also included as a control variable because this variable is closely related with a firm’s capacity to identify and develop new knowledge (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008). A high R&D intensity is connected with broader and more distant search (Mudambi & Swift, 2014).

Search is also facilitated by R&D alliances as they serve as a means for firms to tap external knowledge sources and thereby enhance a firm’s capacity to engage in broader and more distant search (Rosenkopf & Almeida, 2003). To control for the effect of alliances on search, we included the number of R&D alliances in the field of PV a firm was active in one year prior to the year of interest. Since data on the discontinuation of alliances was not available, in line with previous research we assumed alliances to have a duration of three years (Lavie, Kang, & Rosenkopf, 2011).

Mergers and acquisitions, similar to alliances, provide the firm with access to external and thus new knowledge (Arora, Belenzon, & Rios, 2014). To control for this effect, we included the cumulative number of M&A deals a firm had completed in the field of PV at the time of interest.

Employee mobility has also been found to be an important mechanism to help firms overcome local search (Rosenkopf & Almeida, 2003). We therefore included a control variable that for the firm’s patents in a specific year counts the number of inventors that had filed a patent with another firm in the solar industry before.

Firm size is a commonly used control variable because it can affect search in multiple ways, e.g., by facilitating internal collaboration (Leiponen & Helfat, 2010). We measured firm size by including the natural logarithm of the number of employees.

Finally, knowledge search might be driven or hampered by environmental uncertainty. Uncertainty in a firm’s environment may make it difficult for firms to predict future sales and technology developments. On the one hand, such uncertainties may provide an incentive for firms to search for alternatives to existing technologies (Jansen et al., 2006). On the other hand, in the face of uncertainty, firms may postpone investment decisions in innovations and hence reduce their search activities (Hoffmann, Trautmann, & Hamprecht, 2009). In line with
previous work, we used the standard deviation in the change of market size over four years as a proxy for environmental uncertainty (Eisenhardt & Schoonhoven, 1996).

3.4 Model estimation

We used two types of models to assess our hypotheses. For the models including search scope as the dependent variable (hypotheses 1a, 1b, 3a and 3b) we used a negative binominal regression model since the dependent variable takes the form of count data. Generally, negative binominal and Poisson regression models are suitable candidates for the analysis of count data. However, a log-likelihood test of our independent variables pointed to the presence of overdispersion, which can lead to an underestimation of standard errors (Cameron and Trivedi, 2010). Hence, we selected the negative binominal regression over the Poisson model. For the analysis of search distance (hypotheses 2a and 2b) we used fractional logit regression. Fractional logit regression can be used to estimate models with dependent variables that take values between 0 and 1. Two alternative models that can be used to estimate models with such data structure are the beta distribution and the zero one inflated beta. However, in contrast to beta distribution and zero inflated beta, fractional logit regression includes the boundary values (0 and 1) and does not assume zero- or one-inflation.

Hypotheses 1 and 3 were tested with the full sample, i.e. considering all firm-years of the 247 firms over the time period 1988 to 2012 (N=3,480). To test hypothesis 2, we only investigated those firm-years in which we actually observed search activity of firms since measuring search distance is only possible in those years where search takes place (N=745). To control for unobserved variances, we included firm fixed effects. For those models which test the effect of technology-push policies, we also included year fixed effects. Since our demand-pull policy variable takes the same value for all firms in a specific year, using year fixed effects is not possible when testing the effect of this variable. Therefore, for those models that test the impact of demand-pull variables we controlled for time effects by including a trend variable rather than year dummies. In line with earlier studies, all independent variables were lagged by one year. Moreover, for all hypothesis tests we used heteroscedasticity robust estimation techniques. Table 1 shows the descriptive statistics and correlations for all variables.
### Table 16. Descriptive statistics

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<td>0.002</td>
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<td>6.342</td>
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<td>0.18</td>
<td>0</td>
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4. Results

In the following, we separately present the results of the hypotheses tests for the two dependent variables search scope and search distance. For both variables, we first show a base model including only the control variables (models 1 and 8 respectively). Then, we add the two independent variables (demand-pull and technology-push policies) and the interaction effects. As explained above, for both search scope and search distance we tested models with two different operationalizations of demand-pull policies. Models 1 to 11 show the results when using the measure of demand-pull policies based on difference costs. As a robustness check, models 12 to 22 in the appendix report the findings when operationalizing demand-pull policies as market size.

Hypotheses 1a and 1b suggested that technology-push and demand-pull policies are negatively related to search scope. Table 2 summarizes the results of the negative binominal regression models for search scope. As explained above, we tested technology-push policies using a model that contains both firm- and year fixed effects, thereby also controlling for demand-pull policies that are only time-variant (see model 2). In contrast, to test the impact on demand-pull policies, we did not make use of year-fixed effects but included a time trend (see models 3 and 4). The resulting coefficients for technology-push policies in model 2 (β=0.00141, p<0.05) and demand-pull policies in model 4 (β=0.000057, p<0.01) are both negative and significant. Hypotheses 1a and 1b are thus supported by our data.

Table 2. Results of negative binominal model testing effect of innovation policies on search scope

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
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<td>0.359***</td>
<td>0.351***</td>
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<td>(0.0706)</td>
<td>(0.0703)</td>
<td>(0.0713)</td>
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<td>(0.253)</td>
<td>(0.233)</td>
<td>(0.229)</td>
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<td>(0.255)</td>
<td>(0.258)</td>
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<td>Employee mobility</td>
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<td>-0.00347**</td>
<td>-0.00142*</td>
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Table 3. Results of fractional logit model testing effect of innovation policies on search distance

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<th>Variables</th>
<th>Model 8</th>
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<th>Model 11</th>
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</thead>
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<td>(0.155)</td>
<td>(0.158)</td>
<td>(0.157)</td>
<td>(0.160)</td>
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<tr>
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<td>-0.337*</td>
<td>-0.256†</td>
<td>-0.272*</td>
</tr>
<tr>
<td></td>
<td>(0.139)</td>
<td>(0.141)</td>
<td>(0.133)</td>
<td>(0.136)</td>
</tr>
<tr>
<td>Slack resources</td>
<td>0.000122</td>
<td>0.000120†</td>
<td>0.000109</td>
<td>0.000106</td>
</tr>
<tr>
<td></td>
<td>(0.0000766)</td>
<td>(0.0000705)</td>
<td>(7.39e-05)</td>
<td>(7.16e-05)</td>
</tr>
<tr>
<td>R&amp;D intensity</td>
<td>-0.0781**</td>
<td>-0.0843**</td>
<td>-0.107***</td>
<td>-0.110***</td>
</tr>
<tr>
<td></td>
<td>(0.0265)</td>
<td>(0.0263)</td>
<td>(0.0251)</td>
<td>(0.0252)</td>
</tr>
<tr>
<td>Knowledge breadth</td>
<td>0.0164</td>
<td>0.0208</td>
<td>0.0150</td>
<td>0.0171</td>
</tr>
<tr>
<td></td>
<td>(0.037)</td>
<td>(0.036)</td>
<td>(0.0352)</td>
<td>(0.0351)</td>
</tr>
<tr>
<td>R&amp;D alliances</td>
<td>0.134</td>
<td>0.138</td>
<td>0.135</td>
<td>0.135</td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.121)</td>
<td>(0.121)</td>
<td>(0.122)</td>
</tr>
<tr>
<td>M&amp;A</td>
<td>-0.177</td>
<td>-0.181</td>
<td>-0.161</td>
<td>-0.163</td>
</tr>
</tbody>
</table>

Standard errors in parentheses. *** p<0.001, ** p<0.01, * p<0.05, † p<0.1
Hypotheses 3a and 3b suggested that a larger breadth of the firm’s knowledge base reduces the negative effect of technology-push and demand-pull policies on search scope. To test the interaction effects, we used models that include technology-push policy in combination with firm- and year-fixed effects (demand-pull policies are included in the latter). Model 7 lends support for the buffering effect on technology-push policies. The coefficient of the interaction term for technology-push policies and knowledge breadth is positive and significant (β=0.000826, p<0.05). At the same time, however, we do not find support for hypothesis 3b as the coefficient for demand-pull policies is negative and significant (β=-0.0000166, p<0.001).

At the first glance, the effect sizes for the policy variables and interaction effects may appear very small. However, it should be noted that the coefficients in our models are not standardized and that both technology-push and demand-pull funding assume large values. As a result, raising or reducing the funding for innovation policies by a couple of percentage points may already induce firms to change the number and type of sources considered in their search.

The results are almost identical when using market size as an operationalization of demand-pull policies instead of difference costs (see models 12 to 22 in the appendix). As the only difference, in these models the coefficient of technology-push policies in explaining search distance becomes insignificant. In the following we discuss the implications of our findings for the
literature, policy makers and corporate managers. Figure 1 summarizes the findings of our hypothesis test.

**Figure 1.** Summary of impacts of innovation policy on organizational search depending on firm’s existing knowledge base

5. **Discussion**

In the following, we discuss the implications of our findings for the literature. Moreover, we present implications for practitioners, discuss the limitations of the study and suggest some avenues for future research.

5.1 **Organizational search**

This study makes several contributions to the literature on organizational search. First, it broadens our understanding of how factors in a firm’s environment, in particular public policies, influence organizational search for knowledge. Previous research on the antecedents of search has primarily looked at firm-internal variables, such as a firm’s performance and slack resources (Garriga et al., 2013; Laursen, 2012). Only recently have scholars started to investigate the broader environmental context in which this search takes place (Piezunka & Dahlander, 2015; Sidhu et al., 2007). Our study adds to this emerging research stream by showing that
environmental conditions, e.g. in the form of formal institutions, can exert a strong influence on a firm’s propensity to engage in different forms of search. The fact that firms search is affected by the firm’s environment suggests that organizational members may not have as much agency in choosing the firms’ search strategy as the current strategy literature suggests. Instead, in line with the original Carnegie literature, search processes may be conditioned and unconsciously influenced by the environmental context a firm operates in.

Second, our study provides detailed evidence on how technology-push and demand-pull policies influence a firm’s search scope and search distance. More specifically, we find that both technology-push and demand-pull impulses lead to a narrower search scope and that the search distance is positively affected by technology-push policies and negatively affected by demand-pull policies. The former finding supports our argument that by raising the amount of knowledge public innovation policies (1) may allow firms to find a solution to specific problems more quickly, (2) may narrow their attention due to information overload and (3) may raise the opportunity costs of search. As a result, our findings extend previous findings in the literature on the behavioral theory of the firm (Cyert & March, 1963) and crowdsourcing (Piezunka & Dahlander, 2015). In line with the idea of satisficing behavior, firms may primarily invest in search to the extent that is required to solve more immediate problems. A higher amount of knowledge in a firm’s environment may thus not lead to broader search. On the contrary, as more knowledge becomes available, this reduces the amount of search necessary to develop innovations that satisfy the requirements of the firm. In fact, by speeding up the development of knowledge in a technological field, innovation policies may even require firms to narrow down their search to bring products to the market more quickly and avoid “oversearching”. Complementary to this view, recent work on crowdsourcing demonstrates that soliciting large amounts of information may narrow firms’ attention (Piezunka & Dahlander, 2015). It seems possible that public policies show an effect similar to crowdsourcing initiatives at the industrial level. Like crowdsourcing initiated by firms, innovation policies implemented by policymakers may raise the knowledge available to firms but may require firms to reduce their search scope in order to deal with the information overload.

Third, our findings contribute to a better understanding of how a firm’s existing knowledge base influences its search behavior (Zhou & Li, 2012). We find that the influence of technology-push policies on search scope is reduced and the one of demand-pull policies enhanced by a larger knowledge breadth of the firm. A potential explanation for the latter finding might lie in
the different effects that both policies have on innovation. As shown by our analysis of search distance, compared to demand-pull policies, technology-push policies lead to the generation of more diverse knowledge and radical innovations outside existing technologies. If firms possess a broad knowledge, this allows firms to more easily absorb the diverse knowledge generated by technology-push policies. Therefore, we would expect the effect of technology-push policies on the reduction of search scope to be less pronounced for firms with a broader knowledge base. To absorb the relatively uniform knowledge resulting from demand-pull policies, however, a broad knowledge base may be unnecessary or even inefficient. Therefore, in response to demand-pull policies especially those firms with a broad knowledge base might face a strong incentive to reduce their search scope.

5.2 Technology-push and demand-pull policies

Besides contributing to the literature on search, our research also has important implications for the literature on innovation policies. This literature suggests that demand-pull serves as a selection mechanism that fosters incremental innovation primarily within established technological trajectories, whereas technology-pull serves as a variety creating mechanism that may induce more radical innovation (Freeman, 1996; Mowery & Rosenberg, 1979). Although these claims have been taken on in the more recent literature on innovation policies, we currently lack empirical tests that support these propositions. In this regard, to our knowledge this study is among the first to empirically test the influence of technology-push and demand-pull policies on search distance, thereby allowing to draw important conclusions about their potential to foster incremental vs. radical innovations. In line with the predominant view in the literature, we find that technology-push policies exert a positive and demand-pull policies a negative effect on search scope. Despite the fact that technology-push policies may crowd our private R&D funding and that the resulting knowledge may be difficult to decode for firms, it thus seems that such policies can incentivize firms to search in a more distant way. Demand-pull policies, on the other hand, seem to primarily set an incentive for local search despite raising the financial resources available to the firm. In this sense, our findings are in line with recent studies that suggest that demand-pull policies may raise the risk of technological lock-ins (Hopmann et al., 2013).
5.3 Technology life-cycles

Finally, our findings also have implications for the literature on technology evolution and life-cycles. Traditionally, this literature has been interested in understanding the patterns and drivers of technological evolution. It has been pointed out that processes of organizational attention and search may play an important role in the emergence of technological trajectories and paradigms (Kaplan & Tripsas, 2008). So far, however, we lack empirical data describing the ways in which these processes contribute to technology evolution. Our research suggests that as technology-push and demand-pull factors lead to the accumulation of knowledge in industries over time, firms tend to alter their behavior toward narrower search. As a result of searching more narrowly, knowledge becomes increasingly specialized, which may result in the emergence of distinct technological paradigms. Moreover, previous research indicates that industries evolve from being primarily reliant on technology-push factors at the beginning toward a dominance of demand-pull factors in more mature stages (Dosi, 1982). Our findings indicate that as the focus shifts from technology-push toward demand-pull, search of firms may become more local, leading to more incremental innovation. As a result, our findings provide some explanation at the firm level for why innovation patterns over the course of the technology life-cycle shift toward more incremental innovation and may result in the emergence of dominant designs.

5.4 Practical implications

In more practical terms, our study offers some insights for policy makers and corporate managers. We confirm that innovation policies can serve as important means to foster knowledge search and innovation. At the same time, our findings show that this positive effect of technology-push and demand-pull policies comes at a cost since the use of innovation policies can lead firms to consider fewer sources in their search for innovations. Moreover, our results indicate that especially demand-pull policies bear the risk of reducing the extent to which firms search for knowledge outside their focal technology domain. Demand-pull support for firms should therefore be complemented with technology-push support if narrow search is considered undesirable (see also Hoppmann et al., 2013).

For corporate managers, our findings are of relevance as they point to an important role of policies and the firm’s knowledge base for knowledge search. Managers of firms that operate in industries affected by innovation policies should be aware that their firm’s search processes may be easily affected by policy incentives. Especially if firms operate in a country that makes
stronger use of demand-pull policies, this may narrow the firm’s search scope and distance. Since both search scope and distance are positively related to firm innovation and competitiveness (Laursen & Salter, 2006; Salge, Farchi, Barrett, & Dopson, 2013), national policy conditions may negatively affect a firm’s position in international markets. In fact, there is evidence that in the case of the PV industry the strong use of demand-pull policies in some countries, e.g., Germany, might have adversely affected their search behavior (Hoppmann et al., 2013). Our research indicates that a broader knowledge base might be a way to reduce such unintended negative effects of innovation policies on search scope as it allows absorbing more knowledge resulting from technology-push policies. Therefore, if a firm strives to maintain a broader search scope managers might think about deliberately investing in the diversification of knowledge (e.g., by entering new technological fields).

5.5 Limitations and future research

This study has some limitations that may provide starting points for future research. First, our study is limited to the PV industry. While this industry is particularly well-suited to answer our research question, the PV industry differs from other industries in a number of important ways. For example, despite a high propensity to patent, previous research has found a high degree of knowledge spillovers across firms which may influence the patterns of search we observe. Future research should therefore explore the generalizability of our findings to other industries. Second, while our study provides evidence that public policies influence firm search behavior, our research design does not allow us to uncover the relative importance of different mechanisms that lead to our findings. For example, our analysis does not provide insights into whether the reduction of search scope resulting from innovation policies is due firms being able to more quickly find solutions, experiencing information overload or incurring a higher opportunity cost of search. Future research should therefore extend our study by shedding more light on the mechanisms connecting policies and firm search—e.g., by using in-depth qualitative case studies.

Third, since this study is among the first to assess the effects of policies on firm search, we focused on search scope and search distance as the most important dependent variables. Clearly, there are a number of other constructs which represent important dimensions of firm search (e.g. search within vs. across organizations, search across geographical boundaries) or moderating factors (e.g. hierarchical structure). Future research might also categorize the sources of knowledge in terms of inventors (e.g., firms, research institutes, universities,
individuals) and assess how public policies affect the extent to which firms draw on knowledge from different groups.

6. Conclusion

This study investigates the impact of demand-pull and technology-push policies on the search scope and search distance of firms, taking into account the breadth of their existing knowledge base. Our results provide a number of important insights into how firms’ search is affected by public policies. While previous studies show that demand-pull and technology-push policies foster innovative activity and the generation of knowledge, we find that both types of policies lead to narrower knowledge search by firms. Moreover, we provide quantitative evidence that technology-push policies may enhance while demand-pull policies may reduce a firm’s search distance.

We explain these finding by the fact that an enhanced availability of knowledge resulting from policy incentives may allow firms to find a solution to specific problems more quickly, may lead to attention-narrowing information overload and may raise the opportunity costs of search. In this sense, our findings are in line with the traditional literature of the Carnegie School which suggests that actors engage in satisficing rather than optimizing search. Moreover, the finding that technology-push policies lead to more distant, technology-spanning search may be due to the variety-enhancing effect of such policies, which often aim to foster innovation in fields relatively remote from the market. Demand-pull policies, on the other hand, may reduce firms’ search distance as they exert a selection pressure on firms, which induces the latter to primarily pursue innovation along established trajectories.

Overall, our findings provide a first step toward better understanding how factors in a firm’s environment may influence knowledge search. Today, a large number of innovations are developed in ecosystems and supported by public policies. We therefore believe that there are both ample opportunities and a strong need for future studies that deepen and extend the findings presented in this study.
Appendix

Table A1. Keyword used to extract solar PV patents

<table>
<thead>
<tr>
<th>Patent search</th>
<th>Search String</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV patents</td>
<td>IPC=(B23K* OR B28D* OR C01B-033* OR C23C* OR C30B* OR E04D-013* OR H01L-031* OR H01L-021* OR H01L-025* OR H01L-051* OR H02M* OR H02J* OR H02N*-006* OR H01R* OR G01B* OR G01R* OR G05F-001*) AND TITLE/ABSTRACT =(&quot;solar cell*&quot; OR &quot;solar power*&quot; OR &quot;solar module*&quot; OR &quot;photovoltaic*&quot; OR &quot;solar panel*&quot; OR &quot;solar grade&quot; OR &quot;solar electr*&quot;)</td>
</tr>
</tbody>
</table>
Table A2. Keywords used in the categorization of patents

<table>
<thead>
<tr>
<th>Category</th>
<th>Search String</th>
<th>Priority*</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Si PV</td>
<td>“silicon solar cell*” OR “Si-solar cell*” OR “ribbon” OR “Si solar cell” OR “Si substrate” OR “silicon substrate” OR [“ Si “ OR “silicon” OR “Si-solar”) AND (“single crystal” OR “single-crystal” OR “monocrystalline” OR “monocrystalline” OR “crystalline” OR “back surface passivation” OR “rear surface passivation”) OR [“ Si “ OR “silicon” OR “Si-solar”) AND (“polycrystalline” OR “multicrystalline” OR “multi-crystalline” OR “multi-crystalline” OR “poly-crystalline” OR “poly-crystalline” OR “polycrystal” OR “poly crystal” OR “multicrystal” OR “multi crystal” OR “Emitter wrap through” OR “Metal wrap through”)</td>
<td>0</td>
</tr>
<tr>
<td>Thin-film PV</td>
<td>“steel substrate” OR “roll-to-roll” OR “roll to roll” OR “vacuum depos” OR “deposit” OR “vacuum chamber” OR “lama” OR “epitaxially grown” OR “thin film” OR “thin-film” OR “film” OR “plastic substrate” OR “semiconductor film” OR “sputter” OR “glass substrate” OR “flexible substrate” OR “PECVD” OR “PVD” OR “solid phase crystallization” OR “laser crystallization” OR “a-Si” OR “amorphous” OR “micocrystal” OR “silicon-film” OR “Staebler” OR “Cadmium” OR “Telluride” OR “CdTe” OR “CdS” OR “Sulphide” OR “Se” OR “Cd” OR “Te” OR “CIGS” OR “Cl(G)S” OR “indium” OR “selenide” OR “CIS” OR “CulnSe” OR “Copper indium gallium diselenide” OR “CulnGeSe” OR “Copper zinc tin sulfide” OR “CZTS” OR “chalcopyrite”</td>
<td>1</td>
</tr>
<tr>
<td>Third generation PV**</td>
<td>&quot;lens&quot; OR &quot;CPV&quot; OR &quot;concentrator&quot; OR &quot;upconver&quot; OR &quot;up-conver&quot; OR &quot;downconver&quot; OR &quot;down-conver&quot; OR &quot;concentr*&quot;” OR “hot carrier” OR “hot-carrier” OR “GaAs”” OR “Ga-Al-As” OR “gallium arsenide” OR “germanium” OR “crystalline thin-film” OR “crystalline thin film” OR “GaSb” OR “dye-sensitiz” OR “dye sensitiz” OR “organic” OR “dye” OR “nano” OR “nio2” OR “quantum dot” OR “droplet epitaxy” OR “polymer” OR “titanium dioxide” OR “titanium oxide” OR “Graetzel” OR “perovskite” OR [“steel substrate” OR “roll-to-roll” OR “roll to roll” OR “vacuum depos” OR “deposit” OR “vacuum chamber” OR “lama” OR “epitaxially grown” OR “thin film” OR “thin-film” OR “film” OR “plastic substrate” OR “semiconductor film” OR “sputter” OR “glass substrate” OR “flexible substrate” OR “PECVD” OR “PVD” OR “solid phase crystallization” OR “laser crystallization”) AND (“Si” OR “silicon” OR “Si-solar”) AND [“single crystal” OR “single-crystal” OR “monocrystalline” OR “monocrystalline” OR “crystalline”]</td>
<td>2</td>
</tr>
<tr>
<td>Generic</td>
<td>“storage” OR &quot;mounting&quot; OR &quot;roof&quot; OR &quot;solar tracker&quot; OR “fuel cell” OR “inverter” OR ”absorber” OR ”glazing&quot; OR &quot;antireflect&quot; OR &quot;metal evaporation&quot; OR &quot;filter&quot; OR ”Gasochromic”</td>
<td>3</td>
</tr>
</tbody>
</table>

* In the case that an abstract contained keywords of several of the categories, it was assigned to the category with the highest priority since keywords in higher groups indicate work on more advanced technologies. The “generic” category captures the publications on topics that are applicable to all PV technologies.

** Includes concentrating PV, dye-sensitized PV, organic PV, nano PV, c-Si thin-film PV
Table A3. Results of negative binomial regression model on effect of policies on search scope with demand-pull policies operationalized as market size

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 12</th>
<th>Model 13</th>
<th>Model 14</th>
<th>Model 15</th>
<th>Model 16</th>
<th>Model 17</th>
<th>Model 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm size</td>
<td>0.363***</td>
<td>0.359***</td>
<td>0.363***</td>
<td>0.356***</td>
<td>0.358***</td>
<td>0.349***</td>
<td>0.347***</td>
</tr>
<tr>
<td>Financial performance</td>
<td>0.301</td>
<td>0.286</td>
<td>0.171</td>
<td>0.157</td>
<td>0.295</td>
<td>0.290</td>
<td>0.307</td>
</tr>
<tr>
<td>Slack resources</td>
<td>-0.000297***</td>
<td>-0.000295***</td>
<td>-0.000288***</td>
<td>-0.000287***</td>
<td>-0.000282***</td>
<td>-0.000293***</td>
<td>-0.000274***</td>
</tr>
<tr>
<td>R&amp;D intensity</td>
<td>2.64E-03</td>
<td>2.46E-03</td>
<td>0.00215</td>
<td>0.00195</td>
<td>0.00228</td>
<td>0.00288</td>
<td>0.00264</td>
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<td>Knowledge breadth</td>
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<td>0.485***</td>
<td>0.463***</td>
<td>0.465***</td>
<td>0.425***</td>
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<td>0.507***</td>
</tr>
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<td>R&amp;D alliances</td>
<td>0.00876</td>
<td>0.00434</td>
<td>0.000312</td>
<td>-0.00533</td>
<td>0.00610</td>
<td>0.00984</td>
<td>0.0137</td>
</tr>
<tr>
<td>M&amp;A</td>
<td>0.164</td>
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<td>0.205</td>
<td>0.180</td>
<td>0.212</td>
<td>0.169</td>
</tr>
<tr>
<td>Employee mobility</td>
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<td>0.0296***</td>
<td>0.0310***</td>
<td>0.0307***</td>
<td>0.0298***</td>
<td>0.0328***</td>
<td>0.0331***</td>
</tr>
<tr>
<td>Environmental uncertainty</td>
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<td>0.0419</td>
<td>0.0370</td>
<td>0.0339</td>
<td>0.0444</td>
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<tr>
<td>Technology-push policies</td>
<td>-0.00141*</td>
<td>(0.00623)</td>
<td>-0.00165**</td>
<td>-0.00347**</td>
<td>-0.00138*</td>
<td>(0.00623)</td>
<td>0.00405***</td>
</tr>
<tr>
<td>Demand-pull policies</td>
<td>-0.160***</td>
<td>(0.0117)</td>
<td>-0.155***</td>
<td>(0.0118)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology-push policies X knowledge breadth</td>
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<td>(0.000384)</td>
<td>0.00105**</td>
<td>(0.000385)</td>
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</tr>
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<td>Demand-pull policies X knowledge breadth</td>
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<td>(0.00761)</td>
<td>-0.0445***</td>
<td>(0.00770)</td>
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<td></td>
<td></td>
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<tr>
<td>Constant</td>
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<td>-5.976***</td>
<td>-285.5**</td>
<td>-284.9***</td>
<td>-5.893***</td>
<td>-5.930***</td>
<td>-5.817***</td>
</tr>
<tr>
<td>Year fixed effects</td>
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<td>No</td>
<td>No</td>
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<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time trend</td>
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<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Firm fixed effects</td>
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<td>Yes</td>
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<td>AIC</td>
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<td>7968.604</td>
<td>7961.474</td>
<td>7955.489</td>
<td>7927.948</td>
<td>7922.449</td>
</tr>
</tbody>
</table>

Standard errors in parentheses, *** p<0.001, ** p<0.01, * p<0.05
Table A4. Results of fractional logit regression model on effect of policies on search distance with demand-pull policies operationalized as market size

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 19</th>
<th>Model 20</th>
<th>Model 21</th>
<th>Model 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm size</td>
<td>-0.115 (0.252)</td>
<td>-0.106 (0.255)</td>
<td>-0.0908 (0.254)</td>
<td>-0.0740 (0.260)</td>
</tr>
<tr>
<td>Financial performance</td>
<td>-0.498* (0.229)</td>
<td>-0.545* (0.233)</td>
<td>-0.435* (0.217)</td>
<td>-0.476* (0.224)</td>
</tr>
<tr>
<td>Slack resources</td>
<td>0.000197 (0.000123)</td>
<td>0.000193† (0.000113)</td>
<td>0.000165 (0.000120)</td>
<td>0.000158 (0.000115)</td>
</tr>
<tr>
<td>R&amp;D intensity</td>
<td>-0.137** (0.0483)</td>
<td>-0.146** (0.0475)</td>
<td>-0.182*** (0.0442)</td>
<td>-0.188*** (0.0442)</td>
</tr>
<tr>
<td>Knowledge breadth</td>
<td>0.0249 (0.055)</td>
<td>0.0317 (0.0548)</td>
<td>0.0180 (0.0578)</td>
<td>0.0228 (0.0578)</td>
</tr>
<tr>
<td>R&amp;D alliances</td>
<td>0.228 (0.203)</td>
<td>0.235 (0.206)</td>
<td>0.233 (0.208)</td>
<td>0.234 (0.211)</td>
</tr>
<tr>
<td>M&amp;A</td>
<td>-0.303 (0.277)</td>
<td>-0.309 (0.271)</td>
<td>-0.275 (0.278)</td>
<td>-0.280 (0.271)</td>
</tr>
<tr>
<td>Employee mobility</td>
<td>0.00264 (0.00603)</td>
<td>0.00391 (0.00582)</td>
<td>0.000977 (0.00719)</td>
<td>0.00169 (0.00703)</td>
</tr>
<tr>
<td>Environmental uncertainty</td>
<td>0.00749 (0.0176)</td>
<td>0.0111 (0.0181)</td>
<td>0.0247 (0.0175)</td>
<td>0.0252 (0.0176)</td>
</tr>
<tr>
<td>Technology-push policies</td>
<td>0.00129 (0.000799)</td>
<td>0.00129 (0.000799)</td>
<td>0.000727 (0.000649)</td>
<td>0.000727 (0.000649)</td>
</tr>
<tr>
<td>Demand-pull policies</td>
<td>-0.0171** (0.00552)</td>
<td>-0.0185** (0.00568)</td>
<td>-0.0171** (0.00552)</td>
<td>-0.0185** (0.00568)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.22 (1.23)</td>
<td>0.121 (1.251)</td>
<td>3.776 (21.00)</td>
<td>8.742 (21.39)</td>
</tr>
<tr>
<td>Year fixed effects</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Time trend</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Firm fixed effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>745</td>
<td>745</td>
<td>745</td>
<td>745</td>
</tr>
<tr>
<td>Number of Firms</td>
<td>247</td>
<td>247</td>
<td>247</td>
<td>247</td>
</tr>
<tr>
<td>AIC</td>
<td>1417.185</td>
<td>1416.893</td>
<td>1375.279</td>
<td>1379.139</td>
</tr>
</tbody>
</table>

Standard errors in parentheses, *** p<0.001, ** p<0.01, * p<0.05
References


Paper III
From institutional entrepreneurship to differentiation advantage: How firm-specific benefits can emerge from legitimation of non-proprietary technologies

Geng Wu*, Jens Hamprecht, Catharina Bening

ETH Zurich, Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56/58, Zurich, CH-8092, Switzerland

* Corresponding author contact details:

gwu@ethz.ch

Phone: +49 175 318 9190
Abstract

There is a well-established literature examining why and how firms sponsor proprietary technological innovations. However, little attention has been paid to the numerous examples of firms that champion a technology even though it is not proprietary. Since competitors can free-ride on a non-proprietary technology, it is important to understand whether a firm that promotes such a technology gains any firm-specific benefits that are not available to free-riding competitors. This study addresses this gap by examining whether and how firm-specific benefits emerged for a global chemical company that championed several new technologies. The results show a recursive relationship between technology legitimation and the creation of firm-specific resources. The firm that acts as an institutional entrepreneur does not just mobilize resources to change institutional arrangements; it also gains additional resources for technology legitimation as well as competitive differentiation in the very same process. This study contributes to the understanding of how institutional entrepreneurship might confer competitive advantage.

Keywords: Competitive advantage, differentiation, institutional entrepreneurship, legitimacy, resources
1. Introduction

There are a variety of motivations for a self-interested agent to engage in institutional entrepreneurship (Pacheco et al., 2010). One commonly scrutinized motivation is the legitimation of new, proprietary technologies (e.g. Garud, Jain, & Kumaraswamy, 2002; Hippel & von Krogh, 2003; Tracey, Phillips & Jarvey, 2011), whereby the new technology per se grants competitive benefits to the proprietor (Garud et al., 2002). Hence, it is easy to see why firms champion proprietary technologies, although the process is associated with high resource commitment in order to create or alter institutional arrangements (Aldrich & Fiol, 1994; Garud et al., 2002). In our research, we observed one instance of a firm promoting a non-proprietary technology, examples of which include electric vehicles or nanotechnology. Clearly, these may be considered as technology categories that enable the development of the succeeding proprietary technologies of the respective firms (Hsu & Hannan, 2005). Once established, however, the new technology category affects, and is available to, all rent-seekers in the same technological field, and thus constitutes a form of collective good (Barnett, 1990; Hall & Martin, 2005; Spar & La Mure, 2003). Such a collective good implies the dilemma of free-riding, since competitors can benefit from the established technology without investing in the efforts of institutional entrepreneurship (Auplat & Zucker, 2014; Battilana, Leca, & Boxenbaum, 2009b; DiMaggio, 1988; Greenwood & Suddaby, 2006; Hargrave & Van De Ven, 2006; Maguire et al., 2004; Olson, 1965; Pacheco et al., 2010; Panchanathan & Boyd, 2004). Few studies on institutional entrepreneurship have paid attention to this free-riding dilemma; those that have propose concepts for solutions (e.g. Wijen & Ansari, 2007) that merit further empirical examination. Hence, much more can be learned about “the individual benefits that institutional entrepreneurs accrue from their initiatives and the collective benefits that the organizational field enjoys from such actions” (Pacheco et al., 2010, p. 996). In our research, we address this research gap by investigating whether “institutional entrepreneurship action offers an advantage to institutional entrepreneurs over their competitors” (Pacheco et al., 2010, p. 996).

Free-riding dilemmas are well recognized in the literature on open innovation. Scholars have proposed that participating in the research and development of non-proprietary technologies (such as open-source software) can contribute to advantages over competitors—specifically, learning, reputation, and reciprocity (Hippel & von Krogh, 2003; Horbach, 2008; Roberts et al., 2006; Von Krogh et al., 2012; Wasko & Faraj, 2005). Little is known about whether institutional entrepreneurs may accrue these—or other—advantages over their competitors.
from their initiatives. What is more, the mechanisms through which institutional entrepreneurs gain benefits over their competitors remain entirely in a “black box.” In this study we address this gap by asking: How does a firm gain firm-specific benefits from acting as an institutional entrepreneur that champions a non-proprietary technology?

To answer the question from the actor’s perspective (Überbacher, 2014), we conducted multiple nested case studies within a global leader in the chemical industry that consistently plays the role of an institutional entrepreneur legitimizing non-proprietary technologies. We focus on how firm-specific benefits might emerge from acting as an institutional entrepreneur, and assess the competitive relevance of these benefits by drawing on the concepts of the resource-based view (RBV) (J. Barney, 1991; Sirmon, Hitt, & Ireland, 2007; Sirmon, Hitt, Ireland, & Gilbert, 2011). Using theoretical sampling, we scrutinize the cases of electric vehicles, genetically modified organisms, nanotechnology, and biodegradable plastics, all of which represent non-proprietary, novel technologies that depend on sociopolitical legitimacy among relevant stakeholders. Following the analytic induction approach (Manning, 1982), we conduct iterations between theory review and empirical analysis, drawing on data from interviews, archival documents, press articles, and management workshops.

While there is a rich literature on the field-level effects of institutional entrepreneurship (e.g. Greenwood & Suddaby, 2006; Hoffman, 1999; Maguire et al., 2004; Pacheco et al., 2010), our research shifts the focus towards the consequences of institutional entrepreneurship for the entrepreneur Itself. As a consequence, we feel our research offers important contributions to the literature. First, we examine the mechanisms through which the agency of the institutional entrepreneur in legitimating a non-proprietary technology can generate firm-specific benefits. Second, we find a recursive relationship between the resources that the institutional entrepreneur leverages and those that they gain as institutional arrangements change. Specifically, we find that an institutional entrepreneur who draws on practices of cooperation and political tactics to legitimate a non-proprietary technology acquires new resources; the leveraging of these resources supports the further legitimation of the technology. We find that resources that are acquired and leveraged in the process of institutional entrepreneurship can also be leveraged for the differentiation advantage of firm-specific products. Thereby, we contribute to our understanding of how the resource endowments of institutional entrepreneurs in the institutional domain may contribute to differentiation in the competitive domain of the business environment.
Our paper is organized as follows. First, we introduce the literatures examining institutional entrepreneurship and differentiation from competitors. We then describe our research method and the results of our case studies. We conclude with suggestions for theoretical and managerial implications as well as future research opportunities.

2. Theoretical background

2.1 Institutional entrepreneurship for technological innovations

An institutional entrepreneur is a self-interested agent who mobilizes resources to change institutional arrangements (Battilana et al., 2009b; DiMaggio, 1988; Eisenstadt, 1980; Fligstein, 1997; Henfridsson & Yoo, 2013; Maguire et al., 2004). The practices of institutional entrepreneurs can be directed towards dismantling, maintaining, or creating institutions (Hard & Maguire, 2008; Lawrence & Suddaby, 2006). Our focus is on firms as institutional entrepreneurs who work to create and maintain the legitimacy of new technologies (Pacheco et al., 2010). We consider legitimation—i.e. the process of creating legitimacy—as agency that contributes to making a new organizational form—a new technology, practice, or product (Pacheco et al. 2010)—“desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions” (Suchman, 1995, p. 574). While different types of legitimacy exist (Bitektine, 2011), the scope of our research is sociopolitical legitimacy, which is especially important in the emergent, indeterminate fields that coalesce around a new technology (Battilana et al., 2009b; W. R. Scott, 1995). Sociopolitical legitimacy encompasses the concepts of normative and regulative legitimacy (Aldrich & Fiol, 1994): normative legitimacy is reflected in the observance of norms, values, and standards, whereas regulative legitimacy manifests through compliance with formal rules (Scott, 1995; Zimmerman & Zeitz, 2002; Berrone, Gelabert, Fosfuri, & Gomez-Meja, 2008; Deephouse, 1996). Norms are commonly set by actors such as professions or interest groups (W. R. Scott, 1995; Zimmerman & Zeitz, 2002), while rules are set by state agencies that regulate organizations (Deephouse, 1996).

Institutional entrepreneurs are embedded in organizational fields (Seo & Creed, 2002), which can be defined as “a community of organizations that partakes of a common meaning system and whose participants interact more frequently and fatefully with one another than with actors outside the field” (Scott 1995, p. 56). More specifically, a field related to a technological system with “a pattern of relationships among objects and humans related to a product-market domain”
(Garud et al., 2002, p. 197) can be defined as a technological field (Garud & Karnøe, 2003). The work of creating institutions in a technological field demands that the institutional entrepreneur mobilize significant resources (Aldrich & Fiol, 1994; DiMaggio, 1988; Garud et al., 2002; T. B. Lawrence & Suddaby, 2006). The incentive for firms to legitimize a new technology lies in the expected appropriation of rents once the new technology is considered appropriate and desirable in the technological field (Garud et al., 2002). In their efforts to create a new institution, actors draw on practices such as cooperation, political tactics, framing, theorization, and professionalization (e.g. Greenwood, Suddaby, & Hinings, 2002; Lawrence & Suddaby, 2006; Levy & Scully, 2007; Pacheco et al., 2010; Wijen & Ansari, 2007). Garud et al. (2002), for instance, describe the practices of Sun Microsystems in establishing its proprietary Java technology as the common standard in the field of computer programming. However, previous literature has paid only scant attention to the numerous examples of firms that champion non-proprietary technologies, such as electric vehicles or nanotechnology (Auplat & Zucker, 2014). Although such non-proprietary technologies can be seen as a technology category necessary for the later appropriation of proprietary technologies (Hsu & Hannan, 2005), they also raise a “collective good” dilemma, in that competitors can free-ride on the established legitimacy without investing in the costly process of legitimation.

The solution to this free-rider dilemma has been considered in several studies (e.g. Hargrave & Van De Ven, 2006; Hippel & von Krogh, 2003; Wasko & Faraj, 2005). Most of these contributions focus on the case of open innovation, and analyze the motivation of individuals to develop collective goods without immediate proprietary benefits to the contributor. The identified motivations can be intrinsic (e.g. ideology, altruism, kinship, fun) or extrinsic and unavailable to free-riders (e.g. reputation, indirect reciprocity, learning) (Von Krogh et al., 2012). According to Zeitlyn (2003), software engineers participating in the open-source movement value reputational gains over material gains. Similarly, Wasko & Faraj (2005) discovered that individuals contribute to knowledge creation in open forums to enhance their professional reputation, which in turn is expected to advance their career (Stewart, 2003). Another important motivation for participating in the creation of collective goods is indirect reciprocity, which occurs when future cooperation is partly correlated to past experience (Panchanathan & Boyd, 2004; Rockenbach & Milinski, 2006; Shah, 2006). Finally, research on open innovation processes suggests that the development of collective goods contributes to individual learning through “critiques and correction supported by others” (Hippel & von
Krogh, 2003, p. 216), and by gleaning knowledge from other participants during the process (Lakhani & von Hippel, 2003).

In summary, the above-mentioned benefits help to solve the free-rider dilemma of individuals who participate in open innovation. However, little is known about whether these benefits also apply to firms that take actions to change institutional arrangements. Particularly, it remains unclear how firm-specific benefits emerge in the process of institutional entrepreneurship. In order to explore how such benefits can emerge, this study draws on concepts from the Resource Based View (RBV).

2.2 From institutional entrepreneurship to differentiation advantage

Firms that differentiate their product offerings from competitors elicit a superior willingness of customers to pay (Schmidt & Keil, 2013). Such differentiation, along with cost advantages, confers a competitive advantage (Porter, 1985). According to Barney (1991), the source of competitive advantage lies in resources that are valuable and rare; this advantage can then be sustained if the resource is also inimitable and difficult to substitute (Barney, 1991). The resources that meet these criteria are strategic resources that are specific to the firm, and thus contribute to the differentiation of the firm and its products (Barney, 1991; Black & Boal, 1994; Bowman & Ambrosini, 2000; Schmidt & Keil, 2013). The firm can structure, bundle, and leverage these resources in order to obtain sustainable, above-normal returns (Barney, 1986; Sirmon et al., 2007; Wernerfelt, 1984). More specifically, strategic resources support the firm’s efforts to distinguish its own products in order to better meet customers’ demands (Barney, 1986; Bowman & Ambrosini, 2000; Conner, 1991).

Sirmon, Hitt, & Ireland (2007) developed a framework to describe the process of resource management to gain competitive advantage in three steps: structuring, bundling, and leveraging. Structuring refers to the management of the resource portfolio through resource acquisition, accumulation, and divesting. In line with most RBV literature, resource acquisition and accumulation is described as a planned task to gain competitive advantage, such as identification of factor-market inefficiencies and subsequent resource accumulation based on a strategic search and selection procedure (Denrell, Fang, & Winter, 2003; Makadok, 2001; Maritan & Peteraf, 2011; Sirmon et al., 2011). Subsequently, these resources can be bundled to build new capabilities or improve existing ones, so they can ultimately be leveraged to create competitive advantage (Sirmon et al., 2007). A characteristic of firms that pursue differentiation
advantage is that they “commonly try to develop innovation and marketing capabilities” so they can “differentiate their goods (products or services) from those of competitors” (Sirmon et al., 2011, p. 1398). Forms of differentiation advantage in conjunction with new technologies discussed in the literature include new product advantage (e.g. Li & Calantone, 1998), better product reputation (e.g. Rao, 1994), or first-mover advantages (e.g. Makadok, 1998).

3. Methods

In order to explore the mechanisms of differentiation through institutional entrepreneurship in detail, we used a qualitative case-study design. Such a design is especially suited to inductive theory-building through the in-depth understanding of particular events or situations (Eisenhardt, 1989; Siggelkow, 2007). In order to focus on the institutional entrepreneurship process and to control for other contextual factors (e.g. characteristics of a firm’s structural setting for the legitimation process), we conducted multiple case studies through a nested approach within a single firm large enough to provide distinctive cases, but all drawing on similar functions, for the process of institutional entrepreneurship (Eisenhardt, 1989). This also allowed us to repeatedly enter a similar research environment for iterative data collection from multiple sources, such as interviews, workshops, and observations (Eisenhardt & Graebner, 2007; Yin, 2009). Such a data collection process was necessitated by our decision to develop a theoretically grounded model iteratively, based on existing theories, using the analytic induction method (Bansal & Roth, 2000; Manning, 1982).
3.1 Sampling

Adopting a theoretical rather than a statistical sampling approach (Eisenhardt & Graebner, 2007), we conducted our research in one of the largest chemical firms globally, with many prominently and publically discussed innovation cases. With respect to confidentiality agreements on this sensitive topic, we refer to our sample firm as “CHEMCO.” We selected innovation cases that required the legitimation of a non-proprietary technology. In addition, we included cases reflecting both successful and unsuccessful product launches, in order to evaluate whether we observe similar processes despite different outcomes. The success of each project was evaluated by interviewees and, to a large extent, was also publically observable (e.g. through press articles). Therefore, we do not refer to financial performance, but only to whether the product could eventually be launched (e.g. without any public critique of stakeholders). Ultimately, we decided to examine four main cases (cf. Table 1).

Table 1. Case description

<table>
<thead>
<tr>
<th>Non-proprietary technology</th>
<th>CHEMCO products based on the technology</th>
<th>Status of market launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicles</td>
<td>Cathode material, anode material, and electrolyte for Li-Ion batteries - the key component of an electric vehicle</td>
<td>Successful</td>
</tr>
<tr>
<td>Biodegradable plastics</td>
<td>Compostable plastics for use in products such as organic waste bags or shopping bags</td>
<td>Successful</td>
</tr>
<tr>
<td>Nanotechnology</td>
<td>Products based on the modification of materials in the scale of 1–100 nm in order to improve material behavior (e.g. filter, paint) or product efficiency (e.g. computer processors)</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Genetically Modified Organisms (GMO)</td>
<td>Potatoes based on the modification of genes to increase agricultural yield; two attempts initiated in a regional market</td>
<td>Unsuccessful</td>
</tr>
</tbody>
</table>

We paid careful attention to the time aspect of the innovation processes, because project members from our sample firm consistently mentioned different innovation phases in discussions prior to the interviews. In accordance with existing literature, we distinguished between three main innovation phases. The earliest, also called the “fuzzy front end” (Backman, Börjesson, & Setterberg, 2007; Cooper, 2008) or “phase zero,” includes all activities within the innovation development, from the initial idea to conceptualization within a formal process (Verworn & Herstatt, 2007). The intervening phase is characterized by converting the initial idea into a pilot product (Hansen & Birkinshaw, 2007). The final phase is the market launch preparation. We also incorporated the period immediately following launch into this final phase, to investigate immediate stakeholder reactions to the broad introduction of a specific product.
3.2 Data collection

Following the analytic induction approach, we conducted iterations between data and theory. In addition to the required analytic iterations, we also designed our data-collection process in an iterative way. Our approach included screening of press articles, two rounds of interviews, collection of archival data, multiple site visits, joint workshops for results clarification, and application of insights to pilot cases.

First, the research team conducted comprehensive desk research to understand the selected innovation cases. For this, we screened internal archival records from CHEMCO to learn about the different functions that contribute to institutional change processes, and subsequently perused online information as well as external reports. Since our selected cases were well represented in the press, we also screened all media reports from the beginning of the company’s efforts to support the establishment of the technology to date, or until the termination of the innovation process. For the GMO case, for instance, we screened approximately 2000 media articles from 2006 to 2013 using the database of LexisNexis©. The information was then chronologically summarized and every member of the research team was briefed prior to the interviews.

As a second step, we conducted semi-structured interviews with 20 experts and managers within CHEMCO representing the different business and functional areas relevant for our cases. All interviewees received our research description and the interview guidelines approximately one week prior to the interviews. This gave them the opportunity to prepare for the questions. In order to elucidate the process of institutional entrepreneurship for our interviewees, we specifically asked for descriptions of interaction with stakeholders to create acceptance for the new technology. The interviews were semi-structured and allowed enough flexibility to shift the focus towards questions that matched the detailed expertise and experience of the respective interviewee. The interviews lasted between 60 and 90 minutes and were conducted by at least two researchers.

In the third step, we conducted a joint discussion workshop with five CHEMCO representatives from the respective business and functional areas to discuss and validate the emerging constructs and propositions we deduced from the first interview round. The workshop lasted three hours and included open and structured discussions around our emerging frameworks.
In a fourth step, the research team conducted another seven interviews with new interviewees. In total, 15 interviews were conducted on-site and 12 via phone, for a total of 27 interviews (cf. Table 2). All interviews were recorded and transcribed. After this second round, we refined our results, which were again discussed in a fifth step in focus group workshops (cf. Table 3). The data-collection process lasted eight months in all.

**Table 2.** Interviewee description (first and second round)

<table>
<thead>
<tr>
<th>No. of interviewees</th>
<th>Firm function of interviewees</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 1</td>
<td>Round 2</td>
<td>Stakeholder management</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Corporate R&amp;D management</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>Management of sustainability</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Nanotechnology function</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Business unit: Bioplastics</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Business unit: GMO</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Business unit: Batteries</td>
</tr>
</tbody>
</table>
### Table 37. Description of additional data sources

<table>
<thead>
<tr>
<th>Data source</th>
<th>Type of data</th>
<th>Use in analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Press material</strong></td>
<td>• Chronologically compiled press material from third parties (e.g. newspapers, press releases of other companies or associations) related to sample cases, resulting in 280 screened articles  &lt;br&gt; • Chronologically compiled press releases of the sample company</td>
<td>• Gain background information about cases for interviews  &lt;br&gt; • Reflect case progression from the outside (environmental) view to triangulate interview quotes  &lt;br&gt; • Conduct coding of selected press texts to reassess emerging coding constructs from interview transcripts</td>
</tr>
<tr>
<td><strong>Archival data</strong></td>
<td>• Background information about firm processes: firm brochures, websites, and internal documentation of firm internal Stage Gate process  &lt;br&gt; • Case-related documents: presentation and protocols containing case-specific information</td>
<td>• Gain background information about firm-internal structure and processes to put coded constructs in perspective  &lt;br&gt; • Conduct coding of selected text passages (e.g. evidence for political tactics)  &lt;br&gt; • Understand phases of innovation from the firm perspective  &lt;br&gt; • Understand case-progression from the inside (firm) view in addition to interviews</td>
</tr>
<tr>
<td><strong>Focus group workshops</strong></td>
<td>• First workshop: validation of emerging constructs along phases of innovation; discussion of chronological placement of constructs  &lt;br&gt; • Second workshop: validation of all constructs, chronological placement, and relationship among constructs</td>
<td>• Discuss and confirm detected patterns and constructs with case participants  &lt;br&gt; • Discuss and agree on management implications  &lt;br&gt; • Agree on pilot of improved legitimation process</td>
</tr>
</tbody>
</table>

### 3.3 Analytical procedures

We began our data analysis after the first round of interviews. This allowed us to iteratively collect and analyze data in parallel. For the analysis of our data, we followed the approach suggested by Miles & Huberman (1994). First, we created a case database with all the interview transcripts, archival data, and press articles. This database was used to place the crucial events of each case on a timeline. Subsequently, we embarked on the open coding of passages or sentences. The coding process itself was carried out by three researchers independently, using the coding software MAXQDA©. Evaluating inter-coder agreement revealed some minor coding frictions, which were resolved in joint discussions and sometimes resulted in further refinement of our codes.

As a next step, we grouped similar codes and started the axial coding process (Locke, 2001). In several joint meetings, all researchers discussed and agreed on second-order codes resulting from the grouped first-order codes. These second-order codes represented the trends and themes relevant for the development of our theoretical constructs. Hence, we triangulated these codes...
across cases and sources (Eisenhardt, 1989). For instance, for empirical observations and constructs related to CHEMCO individually (e.g. firm-specific resource creation), we used management workshops and individual follow-up meetings with business-unit and functional leaders to triangulate the findings from the interviews. For the empirical observations and constructs related to the field level (e.g. cooperation with stakeholders), we used contemporary press articles and other archival data to validate the effects (cf. Table 3). This triangulation of multiple sources is especially important for our study, as our interview data reflect the processes at a later point in time, whereas the archival data provides actual longitudinal data over time.

With the coded trends and themes, we organized a large management workshop with many of the interviewees and upper management representatives to discuss the accuracy of the constructs and the relationships between them. During this workshop, we actively challenged our findings by asking workshop and interview participants questions such as: “Could it be that the process did not create firm-specific benefits, but rather benefits for the whole industry only?” The documented results of the workshop helped us to further refine our existing codes and to develop a first version of a theoretical framework. This framework results from the relationships among the second-order constructs and a further abstraction of them to theoretical constructs relevant for our research question. Subsequently, we tested our framework and theoretical constructs in follow-up interviews as well as another management workshop.

We concluded our research when theoretical saturation was reached, which we detected in two ways. First, feedback from the final management workshop did not necessitate any further adjustment of our framework. Second, managers successfully validated our framework for other cases using the backtesting method: We asked business unit managers to take our framework and see whether the constructs applied to the historical cases they had experienced. Figure 1 shows the final data structure developed from this analysis.
4. How Chemco gained firm-specific benefits from institutional entrepreneurship for non-proprietary technologies

This section describes our empirical observations and derived theoretical constructs. Figure 2 presents our theoretical framework, which provides an overview of how institutional entrepreneurship leads to the creation of firm-specific resources and, eventually, differentiation advantage. In our cases, we observed various institutional entrepreneurship practices, such as framing and theorization, that were deployed to create and maintain the new technology’s sociopolitical legitimacy (e.g., Greenwood, Suddaby, & Hinings, 2002; Lawrence & Suddaby, 2006; Levy & Scully, 2007; Pacheco et al., 2010; Wijen & Ansari, 2007). However, since this study focuses on firm-internal consequences, we present only those two practices that led to the creation of firm-internal benefits: cooperation with stakeholders and political tactics (Levy & Scully, 2007; Pacheco et al., 2010; Wijen & Ansari, 2007). It is these two practices that contributed to sociopolitical legitimation on the field level, as well as to the creation of networks with stakeholders, knowledge of stakeholder demands, and good reputation among stakeholders at the firm level.
These firm-specific resources fulfilled a dual purpose. On one hand, they were mobilized for institutional entrepreneurship for the non-proprietary technology, and on the other, they contributed to differentiation advantage, which started with the development of firm-specific products in the middle innovation phase. More specifically, we found evidence for these resources contributing to new product advantage, shorter time to market, and good reputation with customers, which can be described as forms of differentiation advantage (Sirmon et al., 2011).

The electric-vehicle case exemplifies the progression from legitimation to commercially exploitable differentiation advantage. The industry platform BATCO was initially founded to facilitate cooperation among stakeholders in order to develop and legitimize electric vehicles. The stakeholder networks developed and the knowledge gained in the context of this platform were later used to defend the legitimacy of the technology when safety concerns arose over the flammability of battery-powered airplanes and cars. In addition, these networks were also leveraged for competitive differentiation of the firm-specific products through faster product approval, or development of products that better met the demands of stakeholders. In the following subsections, we present more detailed evidence for each of our theoretical constructs, as well as the relationships between them.
4.1 Creating and maintaining the sociopolitical legitimacy of non-proprietary technologies

In all cases, we evidenced how CHEMCO conducted cooperation with stakeholders and engaged in political tactics in order to champion the new technology. Cooperation was achieved by identifying and leveraging the common interests of other firms in the value chain, regulatory institutions, industry associations, scientific institutions, or even competitors in order to generate basic knowledge of the technology and facilitate the setting of common standards. Political tactics were characterized by advocacy and public education. Both practices are recognized to contribute to the creation and maintenance of sociopolitical legitimacy, and thus help to further the potential aims of institutional entrepreneurs (T. B. Lawrence & Suddaby, 2006).

Cooperation with value-chain players and regulatory authorities was observed from the early phase of the innovation process on. In the electric-vehicle case, for instance, CHEMCO saw the opportunity to improve battery materials. This was at a time when the German government had initiated funded projects for electric vehicles. In order to realize the identified battery material potential and participate in the public discussion, CHEMCO soon sought out other companies along the value chain in order to discuss product solutions. These discussions, together with support from federal institutions, resulted in joint research projects and the industry platform...
BATCO, sponsored by the German research and education ministry. Important industry players from the automotive industry, as well as major battery system integrators, were members of this platform. The platform facilitated the creation of sociopolitical legitimacy for the new technology, as reflected in the following statement by a director from CHEMCO’s battery division:

We [firms within the BATCO platform] developed a central technology map which shows when we could achieve which results for electric mobility. […] The European regulators adopted the whole concept later on. The map was crucial for our standard setting and very informative for the broader public.

Beside value-chain players and regulatory authorities, other stakeholders such as the scientific community and non-governmental organizations (NGOs) were also invited to join the platform, since the discussions with them helped to clarify the future market and regulative outlook. The cooperation with these stakeholders supported standard-setting for the new technology, and helped to reduce uncertainties.

Political tactics in order to create sociopolitical legitimacy were observed from the middle phase of the innovation process onwards. During this phase, industry standards and public opinions became clearer. In addition, when CHEMCO started to develop its individual end products, regulatory issues also arose. Thereby, we mainly observed public education and advocacy as political tactics to convince the broader public and regulatory authorities, respectively.

Public education was observed through measures such as proactive provision of information to stakeholders, using third-party endorsements, or creating public forums to discuss the new technology. To take the nanotechnology case as an example, CHEMCO worked closely with scientific institutions to develop reliable and trustful test results in favor of the new technology, which could be presented to the general public. In addition, CHEMCO initiated a nanotechnology forum. This forum is used for frequent public discussions and information sessions regarding the latest developments in nanotechnology science. This meant that the broader public could be educated and convinced about the benefits of nanotechnology products. A senior manager from the nanotechnology function stated:
We [CHEMCO] permanently established a forum for nanotechnology in order to inform the public and key stakeholders about the actual harmlessness and advancement of nanotechnology products.

We observed advocacy both by the newly founded technology platforms and by CHEMCO as an individual actor. For instance, to create legitimacy for the new technology, CHEMCO involved regulatory authorities that were already active in the basic scientific discussions of the new technology, and proactively conducted basic tests for or with them. However, advocacy turned out to be especially important in order to maintain legitimacy. For instance, we observed how CHEMCO drew on industry and regulatory contacts established in earlier phases of the innovation process in order to forestall regulatory changes that would seriously hinder the new technology. A senior manager from political affairs stated:

Within a couple of days, negative political opinions snowballed. We decided to collaborate with other firms—also competitors—in order to inform political decision makers about our view […] We [CHEMCO and competitors] divided the workload per federal state and started to conduct ground work with all the relevant decision-makers to avoid an unjustified ban of our products.

In several additional cases, we also observed how cooperation and advocacy were both used as practices to maintain the sociopolitical legitimacy of the technology. In the late phase of the biodegradable plastics case, for instance, the composter association, together with a prominent German non-governmental association (NGO), launched a public and legal campaign against the introduction of compostable shopping bags. By that time, major retailers had already introduced these bags into their ranges. A senior manager from the Bioplastics division said:

We had the product tested in certain counties beforehand with the respective approval from the authorities. However, once we launched the product countrywide with the retail partners, the general claim “biodegradable” came under challenge all of a sudden. The NGO said that this claim was only valid under certain conditions.

This campaign resulted in the withdrawal of all biodegradable shopping bags from a national market. Cooperation with stakeholders and advocacy was then used in order to maintain the sociopolitical legitimacy of the new technology despite the market withdrawal. CHEMCO, as
well as the customers down the value chain, needed to engage with regulatory stakeholders to solve this issue. One senior manager stated:

Later that year, our communication department received signals from the ministry that there might be a new restricting regulation coming up. Some colleagues and I immediately used our networks to talk to politicians in order to prevent further restrictions.

It cost CHEMCO much effort to conduct further tests to prove the biodegradability of the bags and, eventually, to introduce the bags only in areas subject to regulatory and public acceptance. Also, the battery materials and nanotechnology cases indicate that continuous cooperation with stakeholders and political tactics were common practices in the late phase of the innovation process, in order to maintain the sociopolitical legitimacy established earlier on.

In conclusion, we observe that CHEMCO conducted institutional entrepreneurship mainly through cooperation with various stakeholders and political tactics in forms of public education and advocacy in order to create and maintain sociopolitical legitimacy. Tables 4 and 5 present additional exemplary quotes to support our deduction for cooperation and political tactics, respectively. On the firm level, which is the focus of our research, we found evidence that the creation and maintenance of sociopolitical legitimacy also contributes to differentiation advantage inside the firm. These evidences are described in the following subsections.

**Table 4. Cooperation with stakeholders to create and maintain sociopolitical legitimacy**

<table>
<thead>
<tr>
<th>Case</th>
<th>Representative quotes</th>
</tr>
</thead>
</table>
| Electric vehicles | “We initiated together with other firms and political institutions a platform called BATCO, which was supported by federal ministries and academic institutions.”  
“The members of the association reached a common understanding. We then gave a joint statement to the ministries.”  
“The collaboration with industry players along value chain was important for the industry to understand the best solutions in the first place.”  
“We kept contact with the three key ministries. The ministries also had to answer questions from media or public. Hence, they were happy to have our firm as a good discussion partner.” |
| Biodegradable plastics | “We organized a group of industry participants quite fast since we were all facing a common regulation risk.”  
“We decided to found an association involving composters and producers of compostable plastics in order to help establish support for compostable bags in the market.” |
| Nanotechnology    | “We provided our expertise and invited other industry players along the value chain, scientific institutions, but also other stakeholders such as labor unions, schools, and consumer advice centers to join the discussion.” |
Table 5. Advocacy and education as political tactics to create and maintain sociopolitical legitimacy

<table>
<thead>
<tr>
<th>Case</th>
<th>Representative statements</th>
</tr>
</thead>
</table>
| Electric vehicles | “The grounding of an airplane due to battery failures or the burning of an electric vehicle after an accident affected our daily business of course. We then had to answer many questions from various stakeholders [regarding the safety of the product]. We had to come to a joint statement internally and provide our learnings from the safety tests to the press or other stakeholders.” [Public education]  
  “We kept contact with the three key ministries. The ministries also had to answer questions from media or public. Hence, they were happy to have our firm as a good discussion partner.” [Advocacy]  
  “The members of the association reached a common understanding. We then gave a joint statement to the ministries.” [Advocacy]  
  “[…] The support program of the European Union was based on the definitions and ideas we developed earlier with other firms.” [Advocacy] |
| Biodegradable plastics | “Within a couple of days […] we decided to collaborate with other firms – also competitors – in order to inform political decision makers about our view.” [Advocacy]  
  “After the campaign of this NGO against compostable plastics, we arranged a public stakeholder meeting in the capital and invited all critical stakeholders to learn about research findings proving the compostability of our products and to discuss the use of compostable bags.” [Public Education]  
  “We explained the benefits of compostable bags to authorities to avoid compostable bags being banned – as the government planned for conventional plastic bags.” [Advocacy] |
| Nanotechnology  | “We [CHEMCO] founded the nanotechnology-forum relatively early […] to create transparency and inform the broader public. Normally, people do not understand the scientific background of the new technology […] and what we want to achieve with it. Hence, we have to communicate the benefits and solutions of the new technology” [Public education] |
| GMO             | “We [CHEMCO] inform the public about benefits, relevant risks, and potential implications of our biotechnology products and processes, and encourage others to do the same.” [Public education]  
  “People fear what they do not know, so the pure provision of information was one of our valid attempts to establish the technology.” [Public education] |

4.2 Creation of firm-specific resources and the recursive relationship with institutional entrepreneurship

Throughout all cases, interviewees consistently mentioned by-products created in the process of institutional entrepreneurship, which we clearly identified as firm-specific resources. We categorized the mentioned by-products into three resource types: networks with stakeholders, knowledge of stakeholder demands, and good reputation with stakeholders.

Interviewees frequently mentioned lasting relationships, contacts, and broader networks that resulted from cooperation with stakeholders. These networks that were originally set up in the process of institutional entrepreneurship also proved to be useful for firm-specific innovations at a later stage of the innovation process (cf. Table 6). For example, in the nanotechnology case, CHEMCO’s own toxicology department initiated basic toxicity tests to prove the harmlessness
of this nanotechnology. CHEMCO invited firms, authorities, and research institutes to join in the design and execution of these toxicology tests. Besides the effect of sociopolitical legitimation, the firm’s chief toxicologist informed us that these tests resulted in “lasting contacts and relationships with authorities and experts which proved to be useful for the later firm-specific product development and market approval.” The cooperation with authorities in conducting these initial toxicology tests gave CHEMCO useful insights into the kind of tests (and their pass or fail criteria) that authorities would establish later on to evaluate the toxicology of products based on nanotechnology. This example shows how creating sociopolitical legitimacy through cooperation with multiple stakeholders also contributed to resources that could be leveraged for competitive differentiation later on.

Table 6. Building networks with stakeholders through the creation and maintenance of sociopolitical legitimacy

<table>
<thead>
<tr>
<th>Case</th>
<th>Representative quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicles</td>
<td>“Through our industry platform X, which was supported by the federal ministry of education, we had access to a broad consortium of scientific institutions, firms along the value chain, and even firms from adjacent industries.” “You must build a foundation of trust first. This takes time. But once you have it, as we do with Federal Ministry of Economy, Environment, and Technology, they will listen to you and even ask for your advice, as they as institutions also need to stay knowledgeable.”</td>
</tr>
<tr>
<td>Biodegradable plastics</td>
<td>“When we seek acceptance of composters for compostable plastics in a new application, we always talk from association to association. But in that context, we also try to build up the contacts for our own firm.” “To keep the discussions ongoing on the regulation of compostable plastics, we founded an informal network with different federal ministries, authorities and firms.”</td>
</tr>
<tr>
<td>Nanotechnology</td>
<td>“We automatically build a network in the context of the Nanotechnology platform. I mentioned the networks with consumer protection institutions, consumer goods firms, the labor unions. If you provide transparent information to these stakeholders and engage in a dialog, you keep the network alive.” “The joint test collaborations with the authorities also created personal relationships. We are all humans eventually. These people are also the ones calling me for advice on current topics.” “As we worked on scenarios for the European chemical regulations [REACH] we connected to smaller and larger firms along the value chain.”</td>
</tr>
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</table>

Knowledge of stakeholder demands is a second type of resource that interviewees consistently and frequently associated with the creation and maintenance of sociopolitical legitimacy across all cases. The knowledge of stakeholder demands was gained through cooperation with stakeholders. For instance, the industry platform in the electric-vehicle case enabled CHEMCO to gain knowledge about the technical requirements that would best suit the future market. In a joint effort, firms inside the platform, together with political institutions, predicted the future battery technology most likely to offer the optimum balance of power, range, and safety. This joint scenario reduced uncertainty for CHEMCO in its task of selecting the most promising battery material from six options. The cooperation with the automotive industry within this platform also offered further, firm-specific learnings for CHEMCO. A director of the batteries division stated:
The automotive industry for instance mainly employs engineers. The electric vehicle however requires the collaboration between chemists and engineers. Through early engagement with multiple stakeholders from the industry, we learned how to collaborate with engineers most efficiently.

Table 7 presents further examples of how knowledge of stakeholder demands was gained.

<table>
<thead>
<tr>
<th>Case</th>
<th>Representative quotes</th>
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</table>
| Electric vehicles   | “It was interesting to gain knowledge of innovation cycles of other industries. This had implications for our product pipeline.”  
“We had six different chemical options for the cathode material, but we decided on two of them based on prior discussions with stakeholders.”  
“Within the industry platform, we also included other firms across the value chain in order to learn quickly from each other.”  
“The broad information flow with regulators provided us with the opportunity to get a view on the whole vehicle system to understand the needs of players across the whole value chain.” |
| Biodegradable plastics | “We were engaged with many stakeholders in the discussion about the future developments. We discussed where we want to go with this innovation, which criteria are important for the future products, and how we can further improve this innovation.”  
“With time, as the stakeholders got to know us better from several discussions, they would give us information about product demands.”  
“In the process of stakeholder discussion, the customers’ customer told us that their approval for a product depends on specific set of data. Without this knowledge, it would have been difficult to get convincing data in time.”  
“Our toxicology department cooperates with many countries and independent institutions. The knowledge we gain from these tests does not only support the standard development, but also our understanding of products.” |
| Nanotechnology      | “We could understand that the prevention of cadmium discharge was a major stakeholder demand. This changed our development process.”  
“But most importantly, through earlier and broader discussions, we could gain knowledge of the stakeholders at the end of the value chain. This also helped our direct customers, as they often do not know what their end consumer might need in 10 years.” |

A good reputation amongst secondary stakeholders is the third type of resource CHEMCO acquired during the promotion of a nonproprietary technology through cooperation, education, and advocacy. The nanotechnology case exemplifies how CHEMCO’s legitimation efforts created a positive perception of CHEMCO’s specific products. Stakeholders such as the scientific community or regulatory authorities naturally took the product sample of CHEMCO as the reference for the underlying technology. For instance, when the underlying technology gained legitimacy through positive test results, the stakeholders involved in these tests directly endorsed the CHEMCO product tested. A senior toxicologist described the gain of reputation amongst regulatory stakeholders as follows:
Through our early collaboration with political institutions, we have a reputable image on the political stage now. One wants to listen to us now. This also opens doors to people we would not reach before.

Compared to the other two types of resources, good reputation was created in a later innovation phase. There were two reasons for this. First, only through the existence of a developed concept of a firm-specific product, which is normally not available in the early innovation phase, could CHEMCO gain a firm-specific reputation for its own products. Second, a sufficient level of sociopolitical legitimacy as the precondition for a good reputation had to be established first (B. G. King & Whetten, 2008). Table 8 presents further empirical support for cultivating good reputation through the creation and maintenance of sociopolitical legitimacy.

Table 8. Cultivating good reputation with stakeholders through the creation and maintenance of sociopolitical legitimacy

<table>
<thead>
<tr>
<th>Case</th>
<th>Representative quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodegradable plastics</td>
<td>“We have had relationships with farmers for years now. We brought in our know-how to create the industry standard in the earlier phases. The farmers do not blindly trust an ISO standard. They want to see that your product works, and do care about the opinions of their neighboring farmers. These factors cannot be easily copied by our competitors.”</td>
</tr>
<tr>
<td>Nanotechnology</td>
<td>“We get invited to conferences and expert discussions because we conducted many national and internal studies with other institutions. We do also work frequently with authorities. These collaborations gave us a certain scientific credibility.”   \   “We are legitimating nanotechnology with our platform. In this context, some people say that the product of our firm is the current standard or especially trustworthy due to tests from earlier phases.” \   “While many firms cannot get in contact with the authorities, they even come to us for counsel, due to our reputation.” \   “Mrs. X from the Environment Ministry always says that we are her favorite firm to work with. However, this does not help if the underlying technology is in doubt. We are all seen as part of the industry, and we all stand or fall with it.”</td>
</tr>
</tbody>
</table>

Once firm-specific resources were created, CHEMCO mobilized them to aid institutional entrepreneurship for the underlying technology. Our data indicate recursive facilitations between institutional entrepreneurship and resource creation in all four cases, from which we present the electric vehicle case as an exemplar. As we illustrate in the following, recursive effects between institutional entrepreneurship and resource creation were apparent in each of the three phases of the innovation process.

In the early phase of the electric vehicle case in 2007, CHEMCO established networks and acquired knowledge through cooperation with the German Federal Ministry of Education and Research. The regular interaction between these two organizations included knowledge sharing and frequent discussion meetings. Together with efforts of other firms in the industry,
CHEMCO’s mobilization of its knowledge and network contributed to the establishment of a much more extensive research platform in 2008, with a budget of EUR 360 million initiated by the Federal Ministry. This platform was used for the further research and legitimation of the electric vehicle technology.

In the middle phase of the innovation in 2009, CHEMCO extended its network to other leading countries such as the USA. In that year, these networks contributed to the construction of a CHEMCO research and manufacturing center in the USA, where CHEMCO developed its firm-specific product. However, together with other US firms, CHEMCO was also engaged in further legitimation of electric vehicles. By the end of 2009, CHEMCO was one of the organizations selected to receive part of a USD 2.4 billion grant from the US Department of Energy to further develop electric vehicles and associated battery technology.

In the late phase of the innovation process in 2012, several negative incidents involving the combustion of lithium batteries in electric vehicles (e.g. Chevrolet Volt, BYD) and the Boeing 787 Dreamliner put the legitimacy of vehicle batteries in question, as evidenced by the negative press reports during that year. In response, the United States Postal Service (USPS) prohibited the shipping of any devices with a lithium battery to international destinations. Consequently, CHEMCO utilized established contacts and its reputation as a knowledgeable organization to advocate for lithium batteries in the USA. A director of the electric vehicle business unit said:

The regulators banned the transport of lithium batteries. We had to react to that and advocated for our view. Our established relationships and past knowledge creation helped us in the process.

A couple of months later, in November 2012, the USPS lifted the ban. The electric-vehicle case illustrates how the firm-specific networks and reputation with stakeholders also contributed to institutional entrepreneurship for the technology. This recursive relation was observed in all cases (cf. Table 9).

Table 9. Institutional entrepreneurship with firm-specific resources

<table>
<thead>
<tr>
<th>Contributing resources</th>
<th>Case</th>
<th>Representative quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of stakeholder demands</td>
<td>Biodegradable plastics</td>
<td>“From the experience and knowledge gained through the market launch in Japan, we could address all questions from the associations and regulators in the USA faster. We could show Japan as a success case for our launch in the USA.”</td>
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<tr>
<td></td>
<td></td>
<td>“The knowledge we had through our toxicology test allowed us to gain credibility in the standard setting process.”</td>
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</tbody>
</table>

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Networks with stakeholders

<table>
<thead>
<tr>
<th>Networks with stakeholders</th>
<th>Electric vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The establishment of a network not only with customers but also customers’ customers and other stakeholders is important as it supports the creation of market pull later.”</td>
<td></td>
</tr>
<tr>
<td>“The foundation of trust we built earlier with the respective political institutions was useful for shaping political opinion.”</td>
<td></td>
</tr>
<tr>
<td>“We kept contact with the three key ministries. The ministries also had to answer questions from media or public. Hence, they were happy to have our firm as a good discussion partner.”</td>
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</tbody>
</table>

Biodegradable plastics

<table>
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<tr>
<th>Biodegradable plastics</th>
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</thead>
<tbody>
<tr>
<td>“When we discuss innovation, we usually have to establish a relationship before we can discuss details. Thereafter […] we can enter a meaningful dialogue about requirements and exchange information.”</td>
</tr>
<tr>
<td>“Some colleagues had good contacts with members of the agricultural ministry. We leveraged those networks to convince individual decision makers across counties.”</td>
</tr>
<tr>
<td>“Through Mr. X, we could also get to know Mr. Y, who was the deputy chairman of the committee. This helped us to inform him about our firm view and the view of our industry.”</td>
</tr>
<tr>
<td>“We have had relationship with farmers for years. This relationship supported our approval process by agricultural institutes, but also the acceptance of the technology in general.”</td>
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</tbody>
</table>

Reputation with stakeholders

<table>
<thead>
<tr>
<th>Reputation with stakeholders</th>
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<tbody>
<tr>
<td>“Our firm has a good expert reputation. Hence, regulators usually invite us to present our view before setting the standards.”</td>
</tr>
</tbody>
</table>

We conclude that there is a recursive relationship: The process of institutional entrepreneurship contributes to the creation of firm-specific resources such as networks with stakeholders, firm-specific knowledge of stakeholder demands, and good reputation with stakeholders. In turn, firm-specific resources also support institutional entrepreneurship.

4.3 Creation of firm-specific benefits

Our empirical observations suggest that the firm-specific resources that were created in the process of institutional entrepreneurship could be leveraged to contribute to three differentiation advantages: new-product advantage, faster market launch, and a good reputation, specifically amongst customers. We address the generation of these three potential advantages in the following.

Existing literature suggests that new-product advantage can be achieved through better quality, higher reliability, or newness compared to competitors (Li & Calantone, 1998). The development of such an advantage is often based on knowledge of the customers’ demands. However, all four cases displayed the necessity for CHEMCO to know not only the customers’ demands, but also the demands of a broader stakeholder group that could directly influence product features or customers’ demands. We observed that the resources created in the earlier innovation phases contributed to the creation of new-product advantage in the following ways.
First, the technical know-how of stakeholders such as the scientific community or industry players helped CHEMCO improve the design of its firm-specific products. The electric-vehicles case illustrates how market information gained from consumer associations, political institutions, and companies from other industries enabled CHEMCO to optimize the design of its product. A director of the electric vehicle business unit said:

During our engagements with a broader group of stakeholders, we also had intensive information exchanges. We provided technical expertise to the stakeholders and received information about market outlook and regulative trends. In the end, we could, for instance, adapt our R&D towards cadmium, which led to a decisive advantage for our product.

Second, by working together with the whole value chain and political institutions, CHEMCO could develop a product that not only fit the current needs of its direct customers, but also the future needs imposed by other stakeholders such as regulators or customers further down the value chain. Consequently, knowledge of stakeholder demands could be leveraged into new-product advantage.

In cases where the required knowledge of stakeholder demand was not available, or only partially so, existing stakeholder networks played an important role in gaining it. In the electric-vehicle case, for instance, public opinion on electrically powered cars dynamically shifted from support to aversion and back again. The existence of a strong network with industry partners and political institutions from the early innovation phase helped CHEMCO to overcome technological and market uncertainties. With this strong network, CHEMCO could eventually align its product development with the demands of relevant stakeholders along the value chain, and with prospective regulations.

The examples above (and additional evidence as shown in Table 10) provide further indication of how the resources created in the earlier stage of the innovation process can support the creation of new-product advantage.

**Table 10.** Creation of new-product advantage

<table>
<thead>
<tr>
<th>Source</th>
<th>Case</th>
<th>Representative quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of stakeholder demands</td>
<td>Electric vehicles</td>
<td>“We had a broad selection from which we could choose. There are six competing systems. We talked to stakeholders and considered carefully before making the decision. We evaluated the discussions with the stakeholders and decided to go for the two best systems.”</td>
</tr>
</tbody>
</table>
Biodegradable plastics

“We had a choice of two bio-based raw materials for our new product. So we contacted the NGOs and retailers we had got to know from the discussion forums on biodegradable plastics. Based on their feedback we selected one of the raw materials and audited the supply source with an NGO. That helped us launch a product that the retailer felt comfortable with.”

“In a joint effort with many stakeholders, we found out how degradation happens in water. This knowledge also helped our own product development as we needed to know more about degradation in water.”

Nanotechnology

“During the toxicity tests with the authorities we used materials important for the approval of our product. The generated data could then be used for our product. In one case we tested five similar product types and decided to go for two of them based on the test results.”

“In the platform for Nanotechnology, we can discuss various topics with public stakeholders and stakeholders along the value chain. We could use the gained information to further develop our products.”

Networks with stakeholders

“During the toxicity tests with the authorities we used materials important for the approval of our product. The generated data could then be used for our product. In one case we tested five similar product types and decided to go for two of them based on the test results.”

“During the toxicity tests with the authorities we used materials important for the approval of our product. The generated data could then be used for our product. In one case we tested five similar product types and decided to go for two of them based on the test results.”

GMO

“We launched into an environment that we knew, with partners that we knew. But in order to achieve the financial return of the project, we needed to alter scale significantly, which involved bringing more partners into the game. And this is the point where we encountered concerns [rather than interested partners].”

Our cases indicate that creating and maintaining the sociopolitical legitimacy of the underlying technology could increase the speed of firm-specific product approval and thereby shorten the time to market. The importance of being the first in the market was intuitively anchored in the minds of the managers we interviewed. When asked about the advantages of having stakeholders integrated in earlier phases of the innovation process, interviewees frequently mentioned networks or individual relationships with authorities, which were leveraged in the product-approval phase. Personal contacts from earlier phases could speed up the approval process significantly. For instance, officers in the environmental agency have some discretion concerning the timeframe within which they handle any approval step of a new product. However, if the respective officers already knew the firm’s toxicologists from earlier collaborations, they tended to handle the respective firm request much more quickly. Moreover, the knowledge of stakeholder demands influences time to market too. The pilot phase, for instance, often reveals adaptation needs of the product features, which might prolong the development process or even require a redesign of some basic concepts. The necessity for redesign can be prevented through early integration of stakeholder requirements, as one director of stakeholder management explained:
Integrating stakeholders helped us to include the external knowledge into the innovation process. We could then drive the idea generation and product development topics much faster. The combination of external and internal knowledge was needed.

The biodegradable plastics case illustrates what might happen without sufficient knowledge of stakeholder demands. The slogan “fully biodegradable” initiated a wave of complaints from composters and NGOs, because biodegradability is highly dependent on the ecosystem in the natural environment, and cannot be stated as a universal claim without specifying the end-of-life option (such as biodegradation in a composting plant). As a consequence, retailers in one country felt pressured to halt a pilot launch of biodegradable carrier bags. More knowledge of stakeholder demands could have helped to prevent such negative occurrences. These and other representative examples summarized in Table 11 support the finding that the resources created during the creation and maintenance of sociopolitical legitimacy could be used to shorten the time to market.

Table 11. Shortening time to market

<table>
<thead>
<tr>
<th>Source</th>
<th>Case</th>
<th>Representative quotes</th>
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</thead>
<tbody>
<tr>
<td>Knowledge of stakeholder demands</td>
<td>Biodegradable plastics</td>
<td>“We knew that our customers’ customers didn’t like the approval burdens. Hence, we developed a certification system together with an established certifier. This facilitated the market launch for our customers significantly.”</td>
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<tr>
<td></td>
<td>Nano-technology</td>
<td>“As mentioned, the general tests also generated data usable for the product approval speeding up the process.”</td>
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<tr>
<td></td>
<td>General (not case specific)</td>
<td>“We had multiple cases in which all of a sudden the market demand changes and new competitors or customers came into play. We were too focused on our internal research and forgot the stakeholders. As a result, the market access was denied or the competitors were faster than us.”</td>
</tr>
<tr>
<td>Networks with stakeholders</td>
<td>Biodegradable plastics</td>
<td>“In Germany, we have to get the supports for pilots of compostable bags county by county. We could have had this easier if we had had networks with the waste management industry from the outset.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“The relationship, be it with a retailer or politician, can help the business unit. We can launch the final product much easier with a retailer who knows us from the discussions of the technology in the product development phase.”</td>
</tr>
<tr>
<td></td>
<td>Nano-technology</td>
<td>“Since we know each other, the authority members often call me back after certain tests. We have a certain trust base. As a consequence, we work through faster channels. Some things, which might take weeks, are then done in five minutes.”</td>
</tr>
<tr>
<td></td>
<td>GMO</td>
<td>“We could develop the product on our own. The reason to get in contact with stakeholders was clearly the time-to-market effects.”</td>
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<td></td>
<td></td>
<td>“The pilot phase is very affected by the stakeholder initiatives, which are often quite public. Collaborations with stakeholders would have brought us through this phase more smoothly. It would have given us more time to market benefits.”</td>
</tr>
</tbody>
</table>
Customers’ buying decisions are often influenced by the reputation of a certain product (Dawar & Parker, 1994). We see reputation amongst customers as a direct contributor to differentiation advantage, since it has a direct influence on customers’ willingness to pay, as compared to the reputation amongst other stakeholders, which we classified as a resource. As a senior director of the GMO business unit said:

Public opinion does affect the opinion of the customers’ customers and our direct customers. Our customers do not want to risk their reputation if public opinion is negative.

In three of the four cases, third-party endorsements from scientific institutions, political institutions, specialist media, or individual opinion leaders facilitated the reputation of an innovation product even before market launch and, thus, before customers’ product experience. In the biodegradable plastics case, for instance, high engagement in the creation of sociopolitical legitimacy for biodegradable agricultural film built the foundation for the farmers involved also to endorse the firm-specific product at the later stage, since local farmers listen to each other’s opinions. This type of support mainly results from the networks and good reputation amongst the endorsing stakeholders created in the earlier innovation phases.

In addition, we also found that knowledge of stakeholder demands could contribute to the building of reputation purpose. For instance, as a result of CHEMCO aiming to conduct public education through the nanotechnology platform, end consumers formed a positive view of the exemplary product solutions provided by the firm. Table 12 shows part of the evidence supporting our findings.

Table 12. Cultivating a good reputation amongst customers

<table>
<thead>
<tr>
<th>Source with stakeholders</th>
<th>Case</th>
<th>Representative quotes</th>
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</thead>
<tbody>
<tr>
<td>Networks with stakeholders</td>
<td>Biodegradable plastics</td>
<td>“Actually, we had set up the networks with research institutes [affiliated with the agricultural ministry] to get their support for our advocacy for tax reductions. But another outcome of their tests of our biodegradable films was that these research institutes specifically endorsed our product. Over the next few seasons, our business with farmers in the regions around the research institutes grew strongly.”</td>
</tr>
<tr>
<td>Good reputation with stakeholders</td>
<td>GMO</td>
<td>“If a product makes it to the launch phase and is accepted in society and seen as innovative and as a positive contribution by stakeholders, then we can gain some brand benefit.”</td>
</tr>
<tr>
<td>Good reputation with stakeholders</td>
<td>Bio-degradable plastics</td>
<td>“We have had cities that chose to buy compostable organic bags based on our products because they had talked with compost associations. And when the composters told them, ‘CHEMCO’s work best,’ the City authorities opted for our product.”</td>
</tr>
</tbody>
</table>
In conclusion, the empirical evidence supports the view of possible conversion of resources developed during the creation and maintenance of sociopolitical legitimacy into firm-specific advantages, such as new-product advantage, shorter time to market, and good reputation with customers. We consider these types of advantages as contributors to a differentiation advantage.

5. Discussion

So far, literature on institutional entrepreneurship has focused on the field-level consequences of institutional entrepreneurship, such as success, failure, and compromises in the changing of institutional arrangements (Battilana et al., 2009; Pacheco et al., 2010; Hardy & Maguire, 2008; Greenwood & Suddaby, 2006). This study emphasizes the firm-level consequences for the actor. We open the “black box” of how firm-specific benefits emerge during institutional entrepreneurship for a non-proprietary technology. In this section, we discuss the contribution to both theoretical and practical realms, as well as limitations and future research implications.

5.1 Theoretical implications

This study examines how a firm can generate differentiation advantages over competitors by acting as an institutional entrepreneur (Pacheco et al., 2010). As a result, we feel our research makes the following contributions.

First, this study improves our understanding of how institutional entrepreneurship—with effects on the organizational field level—is connected to competitive benefits on the firm level. Previous contributions have focused on the outcome of institutional entrepreneurship by evaluating changes in institutional arrangements, such as the acceptance of a new organizational form (David et al., 2013; Greenwood & Suddaby, 2006). Less attention has been focused on the competitive benefits that might result for the institutional entrepreneur over free-riders (Pacheco et al, 2010). One notable exception has been the research on firms that do not champion a collective good, but rather a proprietary technology. For example, Garud et al. (2002) showed how Sun Microsystems conducted institutional entrepreneurship to gain competitive benefits from its Java technology per se. However, it remains unclear how legitimization of a non-proprietary artifact such as a new, non-proprietary technology, which is prone to free-riding, might contribute to a differentiation advantage for the institutional entrepreneur.
We find that the key underlying mechanism for gaining a differentiation advantage over free-riders is a leveraging of resources from the institutional domain to the competitive domain. Specifically, we observe that resources created in the process of institutional entrepreneurship can be leveraged to gain differentiation advantages. Previous research on institutional entrepreneurship has tended to evaluate resources only in terms of their value in the institutional domain, such as their contribution to a desired institutional change (Battilana et al., 2009). The key to our understanding of differentiation advantages from institutional entrepreneurship has been to expand this traditional scope of analysis to include resource leveraging in the competitive domain. Here, it is worth noting that our findings do not replicate the notion of competitive advantage flowing from the technology per se (since the technologies in our cases were non-proprietary), but rather from the firm-level consequences resulting from that technology. Hence this study provides specific evidence that cooperation and political tactics as practices of institutional entrepreneurship lead to the creation of resources that can eventually contribute to differentiation advantage for the firm’s end products. In our cases, we evidenced how the focal firm involved multiple stakeholders (and even competitors) to develop the basic knowledge, set the industry standards, and shape the regulatory environment. These practices led to two levels of consequences. On the field level, they contributed to the legitimation of new, non-proprietary technologies such as electric vehicles, nanotechnologies, and bioplastics. On the firm level, they contributed to competitive benefits (e.g. new product advantage, shorter time to market, better reputation) for the firm-specific end products based on this new technology.

As its second contribution, this study posits a recursive relationship between the resources that are leveraged for institutional entrepreneurship and those that are acquired through the same process. This recursive relationship might explain part of the further trajectory of the organizational field, as well as part of the variance in firm performance between institutional entrepreneurs and free-riders. Although a recursive relationship between agency and structure is well established (Barley & Tolbert, 1997; Battilana et al., 2009b; DiMaggio, 1988; Giddens, 1984; Pursey P.M.A.R. Heugens, van den Bosch, & van Riel, 2002; Seo & Creed, 2002), most empirical studies focus on unidirectional effects from actors to the field or vice versa. In the one direction, literature depicts the institutional entrepreneur as an actor who mobilizes resources (e.g. social and political skills) in order to produce or change an organizational field (e.g. David, Sine, & Haveman, 2013; Fligstein, 1997; Garud et al., 2002; Greenwood &
Suddaby, 2006; Maguire et al., 2004; Henfridsson & Yoo, 2013). In the other direction, literature has shown how field-level events or institutional pressure determine the actions of, and collaborations among, firms (e.g. Ansari, Fiss, & Zajac, 2010; Hitt, Ahlstrom, Dacin, Levitas, & Svobodina, 2004; Hoffman, 1999).

In a broader context, scholars in the field of institutional work have discussed the reciprocal effects of agency and structure (Pursey P M A R Heugens & Lander, 2009; T. B. Lawrence & Suddaby, 2006; Wijen & Ansari, 2007; Zietsma & Lawrence, 2010). So far, the focus has been on the actor’s actions and material tools, rather than the resources they acquire or use (cf. Lawrence, Leca, & Zilber, 2013; Raviola & Norbäck, 2013; Zietsma & Lawrence, 2010). However, firm-specific resources lead to heterogeneity rather than homogeneity of firms in the organizational field (Deephouse, 1999). The creation of firm-specific benefits by institutional entrepreneurs holds implications for the interrelation between agency and structure in an organizational field. For example, if competitors note that it “pays” to act as an institutional entrepreneur and if, as a consequence, they also start to engage in institutional entrepreneurship, then the trajectory of the institutional change process is likely to change. Our research suggests that the institutional change process could be influenced by whether institutional entrepreneurs accumulate firm-specific benefits or not. This observation provides a new perspective that improves our understanding of the dynamism in the interaction of agency and structure (Deephouse, 1996; Hannan & Freeman, 1984; Pursey P M A R Heugens & Lander, 2009; T. B. Lawrence et al., 2013; W Richard Scott, 1987; Zietsma & Lawrence, 2010).

Our findings also further clarify the possible motivations for firms to promote a non-proprietary technology despite inherent free-rider effects. The firm-specific benefits we identified in the process of institutional entrepreneurship—such as firm-specific networks, or knowledge of stakeholder demands—were not available to free-riders. In contrast, the platform created to support the legitimation of electric vehicles created knowledge and networks accessible by all platform members. These kinds of collective resources do not contribute to differentiation advantage, since they do not fulfill the “rare and inimitable” criteria (J. Barney, 1991). This finding resonates with recent works in the field of open innovation, which show that individuals participating in the development of a collective resource, such as open-source software, can gain specific benefits not available to free-riders. However, these works focus on the individual person as the unit of analysis, not on the firm. Our research suggests that certain benefits accessible to individuals are, to a certain extent, also applicable to firms. CHEMCO improved
its reputation through the stakeholders’ recognition of its legitimation efforts, and also experienced positive indirect reciprocity from stakeholders based on networks established during those efforts. In contrast to the individual benefits described in open-source literature, the spectrum of observed benefits for the firm is more focused. Whereas individual benefits can result from intrinsic (e.g. altruism, fun, kinship) and extrinsic (e.g. reputation, career, pay) motivations (Von Krogh et al., 2012), the firm benefits we found are exclusively extrinsic, as they all serve the purpose of the market launch of the firm’s own product.

5.2 Practical implications

Practitioners have wondered to what extent they should invest in institutional entrepreneurship or focus their resources instead on more “business-relevant topics” and let competitors invest in practices that promote the legitimation of new, non-proprietary technologies. When we spoke with business-unit managers at CHEMCO, almost all were convinced that engagement in the process of institutional entrepreneurship also contributes to some firm-specific advantages; however, they could only elaborate their assumption to a limited extent. Our results specify how certain practices of institutional entrepreneurs, such as cooperation, education, and advocacy, can ultimately contribute to differentiation advantages for the firm. Without the explicit knowledge of a differentiation advantage through institutional entrepreneurship, firms might forfeit a natural and reputable way to generate differentiation advantage (e.g. compared to traditional competitive measures). This opportunity can easily be missed, since firms might be tempted to let competitors do the costly work of legitimizing a new technology and free-ride themselves. By doing so, they can admittedly reap the fruit of the established technology, but not the firm-specific resources and differentiation advantage created in the process.

Second, our framework helps practitioners to understand more clearly the required level of focus along the phases of the innovation process. At an early stage, management should focus their efforts at the field level to contribute to institutional change. We interpret this to mean that adequate engagement in institutional entrepreneurship will naturally lead to creation of resources utilizable for competitive purposes at a later stage of the innovation process. As the firm-specific product development evolves, management attention can shift towards competitive differentiation, since it requires active management in order to bundle and leverage the resources created. For instance, if the business units do not call and collaborate with the toxicology department when it comes to product approval, the contacts and data established during the creation and maintenance of sociopolitical legitimacy might remain unused. Hence,
on the business-management side, firms could systematically introduce guidelines on how managers can connect with departments related to the legitimation process. On the legitimation management (e.g. toxicology) side, firms should anchor the practice of resource creation in the minds of the employees. This can lead to a more conscious creation of firm-specific resources during the legitimation process.

5.3 Limitations and suggestions for further research

We acknowledge the limited ability to generalize some of our findings from multiple nested case studies within one firm. Although we are convinced that the four cases at hand are different enough to conduct cross-case analysis, we deliberately chose a setting specifically suited for our analysis. Hence, our framework mainly targets radical innovations that require sociopolitical legitimation with many stakeholders prior to market introduction. Also, the validity of our findings outside the innovation process context and across organizations from different industries remains to be confirmed.

A second limitation of our study is the measurability of our claimed effects. Financial measures are hardly applicable to our constructs, since the effects lie more in the process than in the financial outcome. However, our research model can be tested in the next step. For instance, the categorization and measurement of resources that are partly, or even completely, attributed to the process of institutional entrepreneurship is potentially achievable. For that, one could compare the resources of polar cases; selecting one firm with a high level of participation in creation and maintenance of sociopolitical legitimacy (e.g. by having dedicated stakeholder integration departments) and another firm with a low level of participation. Also, quantitative approaches could help to detect the mentioned effects. Following the idea of Ray et al. (2004), we recommend measurements at a more detailed level than financial performance.

We see multiple further research opportunities for business scholars. First, we would like to further understand how firms should prioritize between institutional entrepreneurship and other processes focusing on competitive differentiation rather than institutional change. Our findings suggest that institutional entrepreneurship is one approach to achieve both legitimation and differentiation, but we cannot assess the gain in differentiation advantage relative to other approaches. Second, it would be interesting to understand the performance implications of firms frequently engaged in institutional entrepreneurship versus those that are less engaged in such activities, or not engaged at all. Here, quantitative studies could contribute to the understanding.
of the performance variances among firms. Third, building on the ideas of Sirmon et al. (2007, 2011), a deeper understanding of the mechanisms of resource structuring, bundling, and leveraging could provide prescriptive insights. As a first step, our study shows that resource development is possible in the course of other non-competitive efforts, such as the legitimation of a non-proprietary technology. However, the underlying mechanisms facilitating or hampering this development, as well as the subsequent utilization of resources, remain to be explored. To this end, we recommend further in-depth process research within an organization.

6. Concluding remarks

Our cases show how a firm acting as an institutional entrepreneur for non-proprietary technologies can gain firm-specific benefits not available to free-riders. Throughout the phases of innovation, institutional entrepreneurship can facilitate the development of firm-specific resources, eventually contributing to differentiation advantage. In addition, these resources can also contribute to institutional entrepreneurship. Hence, we propose a recursive relationship between institutional entrepreneurship for non-proprietary technologies and the creation of firm-specific resources. The details of these insights reveal different forms of differentiation advantage being created along the phases of the innovation process. As a result, we contribute to the understanding of the consequences of institutional entrepreneurship for the firm (as the actor) and the process of how these consequences emerge. However, despite the existence of firm-specific benefits through institutional entrepreneurship, we also found evidence that managers are not yet consciously developing and leveraging these benefits. Likewise, research in this area is still in its infancy, and we strongly encourage further research at the underexplored interface of the processes of institutional entrepreneurship and competitive differentiation.
References


The process of strategic management of secondary stakeholders: Evidence from four innovation cases

Geng Wu*, Jens Hamprecht, Catharina Bening

ETH Zurich, Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56/58, Zurich, CH-8092, Switzerland

* Corresponding author contact details:
gwu@ethz.ch
Phone: +49 175 318 9190
Abstract

There is evidence that management of secondary stakeholders is often crucial for the success of entire business endeavors. However, the current literature still offers very little insight on when firms conduct various practices for such a strategic stakeholder management. Therefore, stakeholder theorists have requested more in-depth process research on this topic. In this study, we examine how one of the largest global chemical firms conducted stakeholder management during the innovation process of radical, technical innovations. Through inductive research on four innovation cases, we identified distinct practices along different phases of the innovation process. The results not only show categorized practices over time, but also indicate a pattern of gradually moving from cooperative practices together with other firms to individual practices by one firm. Our findings help open the black box of how firms manage secondary stakeholders over time and provide implications for scholars in the field of instrumental stakeholder theory as well as innovation studies. The insights also help managers to prioritize among different practices and to decide on whether to conduct these practices individually as a firm or together with other industry participants.

Keywords: Stakeholder Management, secondary stakeholder, strategic management, innovation, cooperative practice
1. Introduction

“Our confidence in biotechnology has been widely seen as arrogance and condescension because we thought it was our job to persuade. But too often we forgot to listen” said Bob Shapiro, then head of Monsanto (Guardian, 1999). Insufficient involvement of stakeholders can lead to the termination of an innovation, even if it is technologically feasible and scientifically proven to be harmless. In fact, many radical innovation cases experience stakeholder issues because such innovations can be “controversial and potentially disruptive to secondary stakeholders” (Hall & Martin, 2005, p. 274). Hence, the management of stakeholders is especially required during the development of these innovations (Driessen & Hillebrand, 2013; Hall & Vredenburg, 2003; Talke & Hultink, 2010). While primary stakeholders directly in economic exchange with the firm (e.g. customers, direct suppliers) have long been the focus of management scholars, stakeholder theory pays special attention to secondary stakeholders such as regulatory authorities, the broader public, or non-governmental organizations (Eesley & Lenox, 2006). These stakeholders are not directly in economic exchange with the firm but are affected by the firm’s practices. Scholars have found evidence that the appropriate management of secondary stakeholders can have positive effects on return on investment (Preston & O’bannon, 1997), return on assets (Berman et al., 1999), and shareholder value (Hillman & Keim, 2001). Accordingly, the literature on strategic stakeholder management elaborates on the relationship between business performance and the proactive management of stakeholders (Ackermann & Eden, 2011; Berman et al., 1999; Buysse & Verbeke, 2003; A. T. Lawrence, 2010). Neglect of secondary stakeholders can lead to far-reaching, negative consequences for the firm and its businesses (Baron & Hall, 2003; Frooman, 1997; Margolis & Walsh, 2003; Whysall, 2000). Much has been learned about the relation between secondary stakeholder management and business performance, but little is known about how exactly firms manage secondary stakeholders over time (e.g. Ackermann and Eden, 2011; Agle et al., 2008; Harrison and Freeman, 1999).

So far, Driessen and Hillebrand (2013) are among the few scholars looking into the stakeholder management process in-depth with consideration of secondary stakeholders. They define a capability of integrating stakeholders within the new product development (NPD) process and put it in relation to firm performance. Other studies have helped to conceptualize general elements of stakeholder management (Ackermann & Eden, 2011; A. T. Lawrence, 2010). However, these studies have placed relatively little emphasis on describing how stakeholder
management practices can change over time and which of these practices firms can conduct individually and which in cooperation with other firms. In our study, we address these aspects in an innovation context and inquire: How can firms conduct strategic management of secondary stakeholders along the innovation process of a radical technological innovation?

To answer this question, we conducted qualitative research on four innovation cases at one of the largest global chemical firms constantly involved with various innovations in need of extensive stakeholder management. Following the inductive research approach (Eisenhardt & Graebner, 2007; Yin, 2009), we used open and axial coding to analyze interview transcripts, press articles, and archival data related to these cases. Our findings show categorized practices along the phases of the innovation process, which range from the first idea for an innovation to the market launch of the resulting end product (Cooper & Kleinschmidt, 2007; Hansen & Birkinshaw, 2007). Our findings also indicate whether these practices were individually conducted by our sample firm or in cooperation with other firms.

In general, the insights from this study contribute to a deeper understanding of stakeholder management practices as called for by leading scholars in the field (e.g. Ackermann and Eden, 2011; Agle et al., 2008) as well as to the development of practical tools for managers to cope with complex stakeholder issues. The key theoretical contribution of this research is the further extension of the process perspective in the literature of instrumental stakeholder theory (e.g. Ackermann and Eden, 2011; Berman et al., 1999). By opening the black box of corporate management practices over time and comparing these practices among different cases within a firm, we show that the underlying practices of secondary stakeholder management change over time. We also observe patterns of practices potentially instrumental to the introduction of radical technological innovations. Hence, our study also informs scholars in the field of NPD (e.g. Driessen and Hillebrand, 2013). The key practical contribution is to provide managers first suggestions on the sort of stakeholder management practices that can be used along different phases of the innovation process.

This paper is structured as follows: First, we provide an overview of the existing literature surrounding the concept of strategic stakeholder management to characterize the existing literature gap. We then describe our research method to address this gap and introduce the four innovation cases selected. Subsequently, we present the framework derived from our findings and the details on the framework along the three phases of innovation process. We conclude
with a discussion of the academic and managerial implications as well as future research opportunities.

2. Theoretical background

This section first introduces the concept of strategic stakeholder management with special attention to the agents (the who) involved. Subsequently, we provide a brief overview of the detailed constructs of stakeholder management based on existing findings (the what).

2.1 Strategic stakeholder management: firm-individual vs. cooperative strategies

Literature suggests firm-individual and cooperative strategies to strategically manage secondary stakeholders. Both strategies are relevant as firms can seek either legitimation or competitive advantage from such management. So far, the literature suggests that specific issues mostly relevant for one firm can be addressed by the firm individually, whereas complex stakeholder issues with far-reaching effects on the whole industry often require cooperative practices among diverse industry players – even among erstwhile adversaries (Buysse & Verbeke, 2003; Steadman et al., 1995). Firm-individual strategies can contribute to the creation of competitive, firm-specific resources such as knowledge (Harrison, Bosse, & Phillips, 2010a; Lepak, Smith, & Taylor, 2007), reputation (Coombs & Harrison, 2010; Driessen & Hillebrand, 2013; Fischer & Reuber, 2007; Spar & La Mure, 2003), or relational capital (Pike, Roos, & Marr, 2005). Examples of individual strategies include identification and communication to stakeholders in order to champion the firm’s business endeavor and to improve the firm-internal products or processes based on knowledge of stakeholder demands (e.g. Driessen and Hillebrand, 2013; Mitchell et al., 1997; Plaza-Úbeda et al., 2010; Sharma and Vredenburg, 1998). Cooperative strategies can contribute to the legitimation of issues that several firms champion (Agel et al., 2008; Freeman, 1984; Oliver, 1997). Examples of cooperative strategies include industry self-regulation (A. A. King & Lenox, 2000), strategic alliances with competitors, and collaborations with supporting stakeholder groups (A. T. Lawrence, 2010; Steadman et al., 1995). Firm individual strategies can contribute to competitive advantage as well as legitimation of an issue, whereas strategies in cooperation with competitors cannot contribute to competitive advantage. Consequently, the choice between firm-individual and cooperative strategies to stakeholder management has far-reaching consequences for the resource input, need for coordination and the eventual outcome (Astley, 1984; Bresser & Harl, 1986).
2.2 The process of strategic stakeholder management

Although the literature has suggested the importance of both individual and cooperative stakeholder management strategies, the focus of existing studies examining the process of strategic stakeholder management has been on the firm-individual practices. Table 1 provides an overview of studies focusing on the understanding of the strategic stakeholder management practices. Within these articles, we identified four core topics. First, some studies decompose elements of stakeholder management and thus contribute to its further delineation (Plaza-Úbeda et al., 2010; Sharma & Vredenburg, 1998). A second stream of research focuses on how to identify and prioritize relevant stakeholders (Ackermann & Eden, 2011; R. K. Mitchell et al., 1997; Vos & Achterkamp, 2006). Third, authors have proposed general strategies for stakeholder management that depend on stakeholder salience or stakeholder issues (Clarkson, 1995; A. T. Lawrence, 2010). The latter stream of research relates strategic stakeholder management concepts to a specific context (Driessen & Hillebrand, 2013; Driessen et al., 2013; Yip et al., 2013). These studies mostly confirm the specific importance of stakeholder management techniques such as “(1) stakeholder issue identification techniques, (2) coordination mechanisms, and (3) prioritization principles” for NPD (Driessen & Hillebrand, 2013, p. 375). With regard to our research question, which focuses on the what, when, and who of strategic stakeholder management, our literature review (cf. Table 1) reveals two literature gaps. First, existing studies mainly focus on the definition of strategies or high-level practices of strategic stakeholder management (the what), but not on when the detailed practices occur or change over time (the when). Second, literature has paid little attention to the process of cooperative practices to manage complex stakeholder issues (Buyssse & Verbeke, 2003; Steadman et al., 1995). So far, only the study of Lawrence (2010) has touched on the notion of cooperation between the firm and other organizations to solve a stakeholder issue by describing how the firm under scrutiny worked closely with the national government to counteract negative consequences (e.g. delay in product introduction) caused by environmental activists. However, this description was rather a passing comment on many different strategies. This study addresses the literature gaps regarding the what, when and who by examining the strategic stakeholder management practices over time and whether these practices are conducted individually by the firm or collectively with other firms. With regard to the focus on innovations in this study, we use the temporal distinction along three phases commonly applied by NPD scholars (e.g. Cooper and Kleinschmidt, 2007; Crossan and Apaydin, 2010): early, medium, and late. Accordingly, the early phase, also called fuzzy front-end (Backman et al., 2007;
Cooper, 2008), includes all activities of the innovation process from the first idea impulse until the decision of conceptualization within a formal process (Verworn & Herstatt, 2007). The medium phase is characterized by converting the initial idea into a pilot product (Hansen & Birkinshaw, 2007). The last phase is the market launch preparation.

Table 1. Overview of literature related to the process of strategic stakeholder management

<table>
<thead>
<tr>
<th>Main topic</th>
<th>Research method</th>
<th>Main constructs studied (what)</th>
<th>Process along time (when)</th>
<th>Firm-Individual practice vs. cooperation among firms (who)</th>
<th>Core proposition regarding management process</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition of stakeholder management</td>
<td>Quantitative survey analysis</td>
<td>Elements of the stakeholder integration capability</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Proposes three dimensions of stakeholder integration: (1) Knowledge of stakeholders, (2) interaction between a firm and its stakeholders, (3) adaptation of a firm’s behavior to stakeholders’ demands</td>
<td>(Plaza-Úbeda et al., 2010)</td>
</tr>
<tr>
<td>Identification and prioritization of stakeholders</td>
<td>Comparative case studies and survey analysis</td>
<td>Linkage between environmental strategies and the development of competitively valuable firm capabilities</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Describes stakeholder integration as a capability to collaborate with stakeholders, to communicate with stakeholders, and to steer new developments effectively through a public consultation process</td>
<td>(Sharma and Vredenburg, 1998)</td>
</tr>
<tr>
<td>Action research within organizations</td>
<td>Empirical test of concept in four cases</td>
<td>Process to manage stakeholders from the top management’s perspective</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Shows and maps exemplary practices a firm can do to identify the relevant stakeholders, their dynamics, and to develop strategies based on their power and interest</td>
<td>(Ackermann and Eden, 2011)</td>
</tr>
<tr>
<td>Conceptual</td>
<td>Case studies</td>
<td>Stakeholder salience model based on stakeholder attributes and classifications</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Proposes four steps to identify stakeholders in innovation projects</td>
<td>(Vos and Achterkamp, 2006)</td>
</tr>
<tr>
<td>General typology of stakeholder management strategies</td>
<td>Case studies</td>
<td>Typology of strategies dealing with stakeholder disputes</td>
<td>Not specified</td>
<td>Firm-individual and cooperation</td>
<td>Proposes four response strategies depending on the resource-dependence, firm power compared to the stakeholder, and urgency of the issue</td>
<td>(Lawrence, 2010)</td>
</tr>
<tr>
<td>Conceptual with empirical testing</td>
<td>Framework and methodology to analyze corporate social performance</td>
<td>Not specified</td>
<td>Not focus of the study</td>
<td>Develops a typology of stakeholder management by specifying the general posture or strategy for different intensities of stakeholder management (from reactive to proactive)</td>
<td>(Clarkson, 1995)</td>
<td></td>
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</tr>
<tr>
<td>Strategic stakeholder management for a specific context</td>
<td>Case studies</td>
<td>Contextual factors which influence the role of stakeholders in early development phase of product-service system</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Proposes different practices of stakeholder management depending on data and process connectivity of the new product-service system</td>
<td>(Yip et al., 2013)</td>
</tr>
<tr>
<td>Conceptual</td>
<td>Process to coordinate issues from virtual (web 2.0) stakeholder dialogue</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Describes routine-based and communication-based coordination in depth and proposes that the former is better for task-related objectives, whereas the latter leads to more organizational identification by stakeholders</td>
<td>(Driessen et al., 2013)</td>
<td></td>
</tr>
<tr>
<td>Case studies</td>
<td>Elements of stakeholder integration in the new product development process</td>
<td>Not specified</td>
<td>Firm-individual</td>
<td>Defines stakeholder integration as a capability, which consists of (1) stakeholder issue identification, (2) coordination mechanisms, and (3) prioritization principles; It might have a positive impact on competitive advantage through organizational identification by stakeholders</td>
<td>(Driessen and Hillebrand, 2013)</td>
<td></td>
</tr>
</tbody>
</table>

### 3. Research context and methodology

We used a case study design to inductively scrutinize events and situations in-depth (Eisenhardt, 1989; Siggelkow, 2007; Yin, 2009). Since we had little literature guidance regarding the process of strategic stakeholder management over time, we used an inductive research approach to develop theory based on rich, empirical data (Eisenhardt & Graebner, 2007; Strauss & Corbin, 1990).

The innovation process is an especially suitable research context because innovations are new and often controversial among stakeholders, which might lead to “diffusion barriers posed by multiple stakeholder groups on market success” (Talke & Hultink, 2010, p. 537). We conducted our multiple cases within one firm large enough to provide distinctive cases with different stakeholder groups. The firm we investigated is among the leading chemical firms. We refer to
this firm as Gamma. Our focus on this individual firm allowed us to control for other context factors (e.g. organizational structure, industry). Since we conducted theoretical instead of statistical sampling (Eisenhardt & Graebner, 2007), we selected four suitable cases with some selection criteria. Regarding the common criteria, we required all cases to have extensive need for secondary stakeholder management. In addition, all the innovations we analyzed are designed to create new products based on new technologies instead of, for instance, process improvements. Regarding the non-common criteria, we selected both case studies that featured cooperative approaches to strategic stakeholder management as well as cases where the firm acted individually. Furthermore, we considered cases that were considered successful and cases that were considered unsuccessful. The success of a case was evaluated by the status of the market launch of the firm-specific products, which is publically observable (e.g. through press articles). Since we focus on strategic management of secondary stakeholders, a launch without stakeholder issues was rated as successful, whereas launch delay (indicated by the interviewees) or termination due to stakeholder issues was rated as unsuccessful. The selection of the cases fitting our criteria was jointly done by the research team and managers from the sample firm. Table 2 summarizes our case selection.

To understand the cases prior to the field research, we screened 282 media reports with about 52,000 words in total from the beginning of the innovation process until the start of our research in the summer of 2013 (or the termination of the innovation process) using the LexisNexis database (cf. Table 4). For each case, we compiled a dossier chronologically containing all relevant information regarding strategic stakeholder management. This allowed us to repeatedly enter a similar research environment for iterative data collection from multiple sources such as interviews, workshops, and observations (Eisenhardt & Graebner, 2007; Yin, 2009).

Table 2. Case description

<table>
<thead>
<tr>
<th>Case</th>
<th>Description of innovation</th>
<th>Main secondary stakeholders involved</th>
<th>Case summary</th>
<th>Status of market launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Electric vehicle battery materials: e.g. cathode material, anode material, and electrolyte for Li-Ion batteries</td>
<td>Federal authorities, firms along the new value chain (e.g. chemical firms together with engineering firms), Industry associations</td>
<td>Gamma was one of the largest chemical firms to develop batteries for electric vehicles together with many other firms along the value chain. With the support of public authorities, this case presents a best-case scenario for the development and launch of an innovation. However, the legitimacy of this innovation was also questioned in the late innovation process, when vehicles and airplanes experienced security problems with the batteries.</td>
<td>Successful</td>
</tr>
</tbody>
</table>
B  Biodegradable plastics: e.g., compostable plastic bags  Regulatory authorities, industry associations, customers’ customers  Based on biodegradable waste bags developed in earlier years, Gamma later developed biodegradable shopping bags (e.g. for foods retailers). Shortly before the launch of the product, Gamma experienced both issues with public authorities threatening the regulative legitimacy as well as issues with NGOs and industry associations threatening the public acceptance of the technology. With help of third-party endorsers and industry partners, Gamma managed to solve both issues.

Successful

C  Nanotechnology products: e.g., paints that feature particles on a scale of 1-100 nm to improve functional product performance.  Regulatory authorities, media, broader public  Gamma participated in the applied research of nanotechnology and developed many products (e.g. car paint additive, filters, concrete additive) based on it. In the early phase, the industry collaborated to generate a common industry standard and to legitimize the technology. However, when rumors about fine dust issues related to risks for human health emerged, most of the firms removed the label “nanotechnology” from their products. Gamma was the only large firm to try to maintain the legitimacy of this technological innovation. At the time of our research, it was still unsure whether nanotechnology would regain public acceptance.

Success

D  Genetically modified organisms: Modification of genes in plants to increase their yield  Non-governmental organizations (NGO), local activists, media, regulatory authorities  After Monsanto, Gamma was one of the next largest firms trying to establish genetically modified organisms (GMO) for industry production. The scientific tests confirmed the harmlessness of this technology for human health and for agriculture. The regulatory authorities granted Gamma permission to conduct pilot cultivation within the EU. However, due to public resistance catalyzed by NGOs and individual activists, many EU countries banned GMOs, resulting in the termination of this innovation.

Unsuccessful

We conducted semi-structured interviews with senior managers and experts representing the business and functional departments related to our cases. The emerging constructs from the interviews were discussed in two workshops with Gamma representatives from the respective business and functional departments. In total, at least two researchers attended each of the 25 interviews (Table 3); all lasted between 60 and 90 minutes. All interviewees received interview guidelines approximately one week prior to the interviews. The guidelines were flexible enough to adjust the focus towards topics best fitting the respective interviewee.

Table 3. Interview description

<table>
<thead>
<tr>
<th>No. of interviewees</th>
<th>Firm function of interviewees</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Business unit for case A</td>
<td>Business managers responsible for battery materials</td>
</tr>
<tr>
<td>4</td>
<td>Business unit for case B</td>
<td>Business managers responsible for biodegradable plastics</td>
</tr>
</tbody>
</table>
For the analysis of our data, we followed the qualitative approach suggested by Miles and Huberman (1994). The approach involves five major steps of data transcription, coding, themes and pattern identification, shaping propositions, and delineating the deep structure. All interviews were fully transcribed. The coding process itself was done by three researchers independently using the coding software MAXQDA©. The interview transcripts as well as selected press materials were all coded. As a first open coding step, we marked all text passages that indicate a practice of strategic stakeholder management by Gamma. At the end of the open coding round, we had approximately 1500 text passages coded from the interviews alone. These text passages were then categorized into different practice clusters. For instance, quotes such as “we tried to find the stakeholders with positive attitudes towards the technology” (senior manager, case B) or “we have a mapping of people experienced with the respective stakeholder groups” (senior manager, stakeholder management) were categorized as “identification and prioritization of stakeholders.” After the first practice clusters had emerged, we gradually summarized the open codes into pattern codes and subsequently categorized those into our examined constructs (cf. Figures 1 and 2). These pattern codes were further refined with cross-case comparisons and put in relationship to each other via axial coding (Eisenhardt, 1989). With this coding process, we could aggregate the empirical observations to higher-order constructs to derive theoretical and practical implications (Gioia, Corley, & Hamilton, 2013). The research was concluded when we noticed that the incremental improvements to our theory by adding more data or further iterations between theory and data were minimal (Eisenhardt, 1989). To answer our research question, we analyzed the coded practices in two steps. First, we
categorized the practices over time to find out what happened when. Subsequently, we analyzed who conducted the practice – Gamma individually or Gamma with other firms (e.g. value chain partners or competitors). For both steps, we triangulated the practices from the interview quotes with practices described in press material and archival data. Table 4 summarizes the additional data sources beyond the interviews we used for our research.

Table 4. Description of additional data sources

<table>
<thead>
<tr>
<th>Data source</th>
<th>Type of data</th>
<th>Use in analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press material</td>
<td>Chronologically compiled press material from third-parties (e.g. newspapers, press releases of other companies or associations) related to sample cases resulting in 282 screened articles with approximately 52,000 words.</td>
<td>Obtain background information about cases for interviews</td>
</tr>
<tr>
<td></td>
<td>Chronologically compiled press releases of the sample company</td>
<td>Reflect case progression from the outside (environmental) view</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conduct coding of selected press texts to reassess emerging coding constructs from interview transcripts</td>
</tr>
<tr>
<td>Internal archival data</td>
<td>Background information about firm processes: firm brochures and internal documentation of firm internal Stage Gate process. Case-related documents: presentation and protocols containing case specific information.</td>
<td>Gain background information about firm-internal structure and processes to put coded constructs in perspectives.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Understand phases of innovation from the firm perspective</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Understand case progression from the inside (firm) view</td>
</tr>
<tr>
<td>Focus group workshops</td>
<td>First workshop: validation of emerging constructs along phases of innovation; discussion of chronological placement of constructs. Second workshop: validation of all constructs, chronological placement, and relationship among constructs.</td>
<td>Reveal and discuss detected patterns and constructs in the language of managers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discuss and agree on management implications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agree on pilot of improved legitimation process</td>
</tr>
</tbody>
</table>

4. Findings

In this section, we present the overview of our findings with emphasis on two observations: first, we summarize what practices the firm conducted when along the innovation phases. Second, we analyze who conducted these practices: Gamma individually or with other firms collectively. Subsequently, we present the details to our findings along the three phases of the innovation process.

4.1 Strategic stakeholder management along the innovation process: what practices were done when
Figure 1 summarizes the overall findings and shows what practices were conducted when. In summary, we observed nine practice categories: (1) develop basic knowledge, (2) exchange and refine knowledge, (3) define industry standard, (4) strengthen public acceptance, (5) participate in regulatory discussions, (6) support new product development, (7) support product launch, (8) maintain normative legitimacy, and (9) maintain regulatory legitimacy. Each of the practice categories was derived from interview quotes and triangulated with press reports and the firm’s archival data. In this way, categories 1-7 consist of pro-active practices observable across all four cases, whereas categories 8 and 9 (maintenance of legitimacy) are reactive practices observed in some cases.

4.2 Strategic stakeholder management along the innovation process: firm-individual vs. cooperative practices

The second main insight, indicating who was conducting the respective practices – the firm alone or in cooperation with other firms – is described in the following section in more detail.

One senior director summarized the trade-off between individual versus cooperative practice: “We cannot implement competitive strategies too early. First, it is important to gain market acceptance and the technical knowledge together. At the beginning, we mostly make the statements as an industry. When we reach a phase in which we start to develop our own product
In the early phase of Case A\(^1\), Gamma started with a broad collaboration horizontally with competitors as well as vertically with value chain partners to develop the technology know-how and set the standards as a basis for the product development in the later phases (cf. Table A.1). In the medium phase, the industry network continued to conduct cooperative practices to create public acceptance and a favorable regulatory environment for the new technology. However, this was also the phase when Gamma started to position its own product in development and to develop firm-specific relationships with secondary stakeholders. In the late phase, Gamma actively involved secondary stakeholders to get faster product admission and to support a successful market launch of its own products. However, when electric vehicles such as the Chevrolet Volt and the Boeing Dreamliner experienced battery problems leading to the need for maintaining the legitimacy of the battery technology, the industry reacted cohesively. Hence, case A indicates a shift from cooperative to individual efforts from the early to the late phase of innovation process. In the late phase, however, firms horizontally within the industry and vertically across the value chain were observed to join forces again to maintain the socio-political legitimacy of the new technology.

In Case D, Gamma took a more individual approach from the outset of the innovation process. Gamma individually developed the basic innovation without other industry players. In the medium phase, Gamma informed the public on the innovation and engaged individually in regulatory discussions in each of the main EU countries. As a result, Gamma received the EU approval for pilot field cultivation of its products. In the late phase, however, when the field cultivations were in progress, local activists as well as global NGOs questioned the legitimacy of the GMO products and started to conduct protest actions such as occupation or even destruction of pilot fields. Due to the lack of collaborations in the earlier phases, Gamma could not leverage a broad industry platform to maintain the legitimacy of GMO. Even its own value chain firms renounced Gamma’s product as described by one senior Gamma manager: “When we had issues with the public acceptance, our value chain players didn’t support us officially. We were left alone in the discussion.” Gamma individually tried to restore public acceptance with scientific arguments and test results – with no success. Eventually, Gamma had to

\(^{1}\) The cross-case comparison also included cases B and C (cf. Table A.1).
withdraw its innovation completely from the EU market. In contrast to case A, case D displayed no cooperative practices to manage the secondary stakeholders.

Figure 1 depicts the gradual shift from cooperative to individual practices\(^2\) along the innovation process, which turned out to support successful innovation launches at Gamma. Regarding the who, the vertical axis indicates whether each practice category was rather conducted alone by Gamma (i.e. a firm-individual approach) or together with other firms (i.e. a cooperative approach). Thus, our data indicate that four categories contain almost exclusively firm-individual or cooperative practices, whereas five practice categories contain a mix of cooperative and firm-individual practices. Figure 2 summarizes the empirical references as described above to the derived practice categories along the phases of the innovation process. The following subsections present the detailed findings on the practices for each of the three innovation phases.

\(^2\) Figure 1 indicates the initial occurrence of different practice categories, but not their duration. The practice categories are not limited to the shown phase but can endure to other phases.
4.3 Early phase – develop basic knowledge and a common industry standard

At the beginning of the innovation process, Gamma was mainly concerned with the development of technical knowledge in all cases. A senior director responsible for case A exemplifies: “Everything was new to us when we started five years ago. We discussed with firms across the value chain and with competitors on various conferences and forums.” At the beginning, Gamma and other firms jointly established the basic knowledge required to develop a product out of the innovation idea. It was not yet the knowledge required to differentiate their own product and hence not competitive knowledge. For instance, managers told us that the range requirements and the allowed spatial dimensions of a battery needed to be defined first, before consideration of the best chemical materials for the cathode and anode (which would

<table>
<thead>
<tr>
<th>Phase</th>
<th>Practices with secondary stakeholders</th>
<th>Empirical observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>Development of technical knowledge (cooperative)</td>
<td>• Understand basic knowledge</td>
</tr>
<tr>
<td></td>
<td>Exchange and refinement of knowledge (cooperative + individual)</td>
<td>• Identify stakeholders for knowledge exchange</td>
</tr>
<tr>
<td></td>
<td>Development of industry standard (cooperative + individual)</td>
<td>• Inform and educate target stakeholders</td>
</tr>
<tr>
<td></td>
<td>Development of public acceptance (cooperative + individual)</td>
<td>• Understand stakeholder demands</td>
</tr>
<tr>
<td>Medium</td>
<td>Participation in regulatory discussions (cooperative + individual)</td>
<td>• Set up key stakeholder relationships</td>
</tr>
<tr>
<td></td>
<td>Improvement of new product development (cooperative + individual)</td>
<td>• Define institutional boundary</td>
</tr>
<tr>
<td>Late</td>
<td>Maintenance of normative legitimacy (cooperative)</td>
<td>• Organize industry participants</td>
</tr>
<tr>
<td></td>
<td>Maintenance of regulatory legitimacy (cooperative)</td>
<td>• Set common standards</td>
</tr>
<tr>
<td></td>
<td>Support of own product launch (individual)</td>
<td>• Inform and educate broader public</td>
</tr>
</tbody>
</table>

Figure 2. Observed practices from empirical data
already be a competitive consideration). One can see this kind of knowledge development as the step from scientific lab to industry application. Since this development of knowledge was relevant to a whole industry, it is often supported by public authorities or governments. In this case, for example, the Federal Ministry of Education and Research not only funded a research project, but also brought together the key value chain players from material supplier to the original equipment manufacturer (OEM) to initiate a joint research platform: “The program developed into a publically funded project. The Federal Ministry of Education and Research were the key sponsors. The scientific community, battery manufacturers, system integrators and OEM all participated” (senior manager, case A). Collaborations among the firms to develop the basic knowledge were also observed for the cases B and C. In case D, however, Gamma was the only firm thinking about the implementation of its innovation at the time and thus acting on its own.

Once the basic knowledge had been developed, Gamma started with the exchange and refinement of knowledge with relevant secondary stakeholders outside of the core industry. As a first step, Gamma identified the relevant stakeholders for the respective innovation. Our interviewees consistently stated that public authorities and governments as well as the scientific community had the “right to be involved” or “are the ones who lay the ground for the innovation in the first place.” In addition, Gamma managers recommended involving positively minded stakeholders first since these stakeholders were more inclined to constructively discuss the requirements for the innovation without being prejudiced or emotionally bounded. Once the relevant stakeholders had been identified, Gamma engaged with other firms in knowledge exchange and discussion with these stakeholders. Such an exchange mainly consisted of informing stakeholders about the current state of research and receiving their demands for the further development. Exchange platforms mentioned include conferences, discussion forums, and bilateral meetings. In cases that Gamma judged successful, the identification and education of stakeholders were done in cooperation with other firms to share the cost and to gain scale. The knowledge exchange also incorporated individual practices of the firm. Besides the basic demands for the underlying technology, Gamma could gain an understanding of the stakeholder demand usable for the competitive differentiation of its own product later in the process. For example, in case C, toxicologists participated in the first exposition tests of nanotechnology products and built long-lasting relationships with people from the public admission office. These relationships turned out to be useful for faster product admission in the late phase. A
senior manager from the toxicology department stated: “We found the nanotechnology forum to initiate a nation-wide network. Without such a network, one cannot inform stakeholders through effective channels and react to later issues. [...] The persons we get to know from such networks were sometimes also important stakeholders later in the process.”

Once the practices of knowledge development and exchange were initiated, Gamma participated in the development of industry standards. In this way, Gamma and the firms involved in the initial knowledge discussion were, together with public authorities and governments, actively defining the industry boundary. For example, by defining the requirements for the label “compostable,” Gamma could exclude dubious firms with lower standards: “Initially, we collaborate with competitors, who had similar ethics as us to create a certain standard” (senior manager, case B). In case A and C, the firms involved in the innovation also organized themselves in order to coordinate the tests and agree on the future process to develop end products along the value chain. Once the industry and the form of industry collaboration were shaped, the concrete standards were codified in different forms such as technological roadmaps, technical criteria agreed on with public authorities, or formal guidelines set by public authorities: “It took a while for all firms to agree on a common standard [...] but eventually, we (material, battery and automotive manufacturers) developed a common concept. This concept had weight because it was developed by the largest firms in the industry” (senior manager, case A).

4.4 Medium phase – develop the market

In all four cases, the development of knowledge and industry standards was followed by actions with the purpose of developing public acceptance and participation in regulatory discussion relevant for the innovation. The two main practices to create public acceptance with secondary stakeholders were providing information about the innovation to the public and getting secondary stakeholders to endorse the innovation publically. One business director had the experience that “people fear and perceive risks in things they do not know about.” Case A is a best practice example, in which Gamma in collaboration with the federal government and the manufacturing industry informed about the potential benefit (e.g. CO2 mitigation, noise reduction) and risks (e.g. limited range, security and reliability issues with batteries) of electric vehicles. However, in another case study (case D), Gamma had to conclude that “it turned out that most of the secondary stakeholders did not really know what [the technology] means” (senior manager, case D). Endorsements from secondary stakeholders not belonging to the
industry helped to support the credibility of the innovation: “Scientific publications are highly respected by the media and hence the broader public” (senior manager, case C). The mentioned stakeholders most suitable for public endorsement were scientific institutions, public authorities, and NGOs. Gamma managers often mentioned the importance of having the right balance between emotional and rational communication. For example, the communication on GMOs was not simple for the broader public to comprehend and also not as convincing as emotionally loaded claims from NGOs. A senior manager stated that “one cannot overload the public with facts. The GMO topic was emotionally linked to food and hence highly difficult to communicate.” At the same time, the innovation needed to be adopted locally by farmers. Without such a local acceptance, it was also difficult for political stakeholders to grant favorable regulations.

In many ways, the participation in regulatory discussion involved similar practices as in the development of public acceptance. Providing information and education to authorities and governments as well as gaining credibility through third-party endorsements were also common practices encountered in regulatory discussions. The difference is that the target stakeholders were clearly defined. For all cases, there were authorities on the regional, national, and EU levels to be convinced. In the cases that Gamma judged as successful, advocacy to convince these stakeholders was conducted in cooperation with other firms.

These discussions with various stakeholders also proved valuable for the next practice, the improvement of new product development. In case C, a senior manager stated: “We tested five different product types. Based on the feedback of various stakeholders, we decided to proceed with the two most promising ones.” In addition, Gamma learned about the processes and cultures of distant value chain firms in order to optimize their own research and development. In case A, the collaboration with OEMs, which are not the direct customer of Gamma, improved the mutual understanding regarding the way of working and the different mindsets among chemists and engineers: “The automotive manufacturers mostly employ engineers. We are chemists. Engineers and chemists think very differently. The collaboration in the electric vehicle platform brought engineers and chemists together [...] so we can learn from each other and collaborate more efficiently” (senior manager, case A).

4.5 Late phase – maintain legitimacy of the technology and support product launch
In the late phase of innovation process, Gamma was mainly concerned with preparing the market launch of its own products and maintaining the legitimacy of the new technology. Since the risks and benefits of the products became increasingly clearer as market launch approached, secondary stakeholders also became more active in giving opinions for or against the new technology. In the cases where stakeholder management turned out to be successful, Gamma managed to switch between cooperative practices to maintain legitimacy of the new technology and individual practices to promote the firm’s own product.

Regarding the maintenance of the normative legitimacy, the successful cases provide evidence that continuous monitoring of stakeholder dynamics and the continuous provision of product information helped to anticipate and alleviate concerns of stakeholders. In case B, a senior manager described how Gamma’s stakeholder managers “conducted a kind of influence mapping. The goal is to know with who I need to talk next and how to avoid bad surprises.” In case A, the national platform initiated in the early innovation phase helped to understand current public opinion and to inform stakeholders about the progress of the technology development. When issues arose from the ignition of batteries in China and in the USA, the platform coordinated joint responses of various firms and collaborated with public authorities to examine and improve the flammability issues. In case D, Gamma did not have any platforms with which to react in cooperation with others to stakeholder issues. Even its own value chain avoided public commitment to the innovation. Hence, when activists started to occupy agricultural fields with the support of NGOs, Gamma had to defend the legitimacy of the technology on its own.

Active monitoring of the stakeholder opinions was also needed for maintenance of regulatory legitimacy. The channels to conduct the monitoring were mostly based on networks with public authorities. Once regulatory issues emerged in case B, the industry established a common standpoint and shared the burdens to conduct advocacy at multiple levels. A senior public affairs manager described the process as follows: “We shared the work among firms and associations. The association had a good relationship with the communal authorities in one state, three firms were working with the authorities in another state and I personally had a good relationship with a third state […].”

Whereas maintenance of normative and regulatory legitimacy were done in a cooperative manner in the successful cases, getting the support of own product launch from secondary stakeholders was a firm-individual effort. In the cases B and C, Gamma could use the network
with public authorities to accelerate product admission. For instance, authorities have the discretion to handle any admission step (such as the confirmation of test results) within a time frame of a few weeks. The trust that experts in Gamma had gained among public authorities in earlier collaborations could help to have requests from Gamma handled much faster: “We know and work with each other for a long time. So when I submit a risk evaluation report to the authority, I will instantly get a feedback call instead of a letter, which might take days or weeks” (senior manager, case C). A second firm-specific benefit achieved with stakeholders was the knowledge of the adequate product launch communication. Case B experienced issues when the retailers claimed that the new bags were “biodegradable,” which cannot be universally claimed for all environments. While the bags were technically proven to be compostable in composting plants, the composters did not believe this was the case. “We should have involved the composters in our discussions earlier in order to avoid such miscommunications,” said one business manager responsible for case B.

5. Academic implications

Existing literature focuses on identifying what practices constitute strategic stakeholder management. The findings of existing literature are therefore typically not contingent on when practices occurred across time (A. T. Lawrence, 2010; Plaza-Úbeda et al., 2010). This study shows the importance of integrating a temporal perspective on the different practices. The elements of strategic stakeholder management differ significantly across time. In our cases, strategic stakeholder management in the early phase of the innovation process mainly means working together with industry players and secondary stakeholders to get the necessary fundamental knowledge and to set a common standard, whereas strategic stakeholder management in the late innovation phase is about practices to prepare a successful market launch of the firm-individual product and to maintain the acceptance of the technology. Hence, when one asks about what defines strategic stakeholder management, one should also ask about the temporal scope (the when) in order to receive a more adequate answer.

In addition, our study informs management scholars about the importance of understanding the trade-off between individual and cooperative practices to manage secondary stakeholders. This trade-off was a consistently observable pattern throughout our cases and was also directly indicated in various interview quotes. By examining both individual and cooperative practices with competitors, we could evince the managerial concerns regarding this trade-off. Scholars have discussed integrated strategies of cooperative and individual approaches on a high level
(e.g. Baron, 1995; Fremeth and Richter, 2011), but still lack the concrete link of the strategies to specific practices. This study provides such a link and hence contributes to the further understanding of who – the individual firm or a collection of firms – was involved in practices of strategic stakeholder management. Following the request for more in-depth process research on stakeholder management (e.g. Ackermann and Eden, 2011; Agle et al., 2008; Harrison and Freeman, 1999), the combined understanding of when and who to conduct what practices along the innovation process is one way to further open the organizational black box of strategic stakeholder management.

6. Managerial implication

Our findings hint at three main managerial implications. First, our interviews indicate that firms can benefit from the development of broad collaboration platforms among firms (even including competitors) in the early phase of the innovation process. These platforms can help to respond to stakeholder issues related to the overall technology, which are often too complex or too burdensome for one firm to address alone. In our cases, such an early development of collaboration platforms was not yet actively driven by the firm. In cases A and B, for instance, the platforms were created through policy measures (e.g. the federal initiation of an electric vehicle platform) or incidental events rather than by strategic management of the firm. Hence, for innovations which might experience high public or regulatory attention, a proactive development of such platforms could contribute to a successful market launch. The two successful cases display how institutionalized platforms as well as informal relationships based on collaborations in the earlier phases are both proven to be adequate for organizing cooperative practices later in the process. Whereas broad and institutionalized platforms were observed to be useful for solving public issues at a certain scale, trust-based, informal relationships based on earlier collaborations were observed to be useful for solving regulatory issues. This is because regulatory issues often involve a clear and limited number of stakeholders, whereas public issues require large-scale effort and thus higher resource commitment.

Second, the shift from cooperative practices to firm-individual practices along the phases of innovation process in the successful cases indicates the importance of changing the management focus from cooperative to individual strategies over time. For instance, firms might be tempted to develop the knowledge on their own. However, our cases show that such an individual effort might not be needed at the early, fuzzy stage because the knowledge developed there is often too basic for competitive product differentiation. Therefore, sharing
the cost of basic knowledge development might be the better solution. In contrast, managers could try to focus on individual efforts once the product specifications are mature enough for competitive differentiation.

Third, our framework codifies the most evident practices observed in four cases. The details of this framework including the time and types of practices provide guidelines for a process relatively new to firms. Taking this framework as an initial template for further refinement, firms can codify their learning about strategic management of secondary stakeholders from the various innovation cases. This would help managers responsible for the innovation process to better understand when to involve which stakeholders for the respective practices. To our knowledge, such a systematic execution of secondary stakeholder practices in the innovation process is not yet common management practice.

7. Conclusions, limitations, and future research

This study examined the practices a firm conducts to manage secondary stakeholders across the phases of the innovation process. Based on comparison among the more and the less successful cases, we found evidence that a shift from cooperative to individual practices along time and the switch from individual to cooperative practices to maintain the legitimacy of the technology might be beneficial for the launch of an innovative product. Based on our literature review, our study is among the first to open the corporate black box of secondary stakeholder management along the phases of the innovation process. Thus, this study contributes to the requested explanation of how the instrumental stakeholder theory can be applied in practice and how the detailed practices change over a certain period of time such as the innovation process (e.g. Ackermann and Eden, 2011; Agle et al., 2008; Harrison and Freeman, 1999). Our study also helps managers prioritize among practices conducted cooperatively with competitors and value chain players and practices conducted individually.

There are some limitations conditioned by the examination of four nested case studies. First, since we focused on in-depth process research, which does not generate data broad enough to make comprehensive and generalizable claims, we regard our derived practices as the most evident ones, but not necessarily exhaustive. Second, there are some limitations resulting from the context of the type of innovation, industry, and firm underlying our empirical sample. The innovations in all four cases were dependent on public perception, which is not applicable to all innovations. For less radical innovations or innovations not relevant to end consumers (such
as specialized business-to-business products), we expect fewer practices to help achieve public acceptance and maintenance of legitimacy. As a result, our pattern from cooperative to individual practices might be less relevant for those innovations. The chemical industry is usually subject to frequent regulations due to the risks associated with new products. Firms in this industry tend to have stronger networks and more frequent interactions with regulatory authorities than firms in industries less affected by regulations. Hence, the practices targeted to help create regulatory legitimacy might be less relevant for industries with less frequent regulatory interventions (e.g. entertainment, retail, textile industry). Gamma is among the largest firms within the chemical industry. Gamma aspires to be among the market leaders with its product lines and is thus highly engaged in the process of standard setting and legitimation of new technologies. This might be different among smaller firms, which strategically plan to be market followers instead of market leaders.

This study provides multiple starting points for further research. Based on the identified practices, quantitative research testing the existence of these practices across other major industries including different sizes of firms and different types of innovations can be one possible avenue of research. Here, the results might not only clarify the generalizability of our findings, but also show the variance of some constructs across innovations, industries, and firms. Another way would be more in-depth process research at a firm in a polar setting to Gamma. It would be interesting to see how small firms within a stable regulatory environment manage secondary stakeholders along the innovation process. In general, strategic management of secondary stakeholders has become a more salient topic over the past years and hence provides an exciting new area of study for scholars.
## Appendix

### Table A.1. Cross-case evidence for collective vs. individual practices

<table>
<thead>
<tr>
<th>Practice category</th>
<th>Early phase</th>
<th>Medium Phase</th>
<th>Late phase</th>
<th>Status of market launch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Develop basic knowledge</td>
<td>Exchange and refine knowledge</td>
<td>Develop industry standard</td>
<td>Participate in regulatory discussions</td>
</tr>
<tr>
<td>Case A (actual strategy)</td>
<td>Collective platform with industry and government (C)</td>
<td>Industry platform, support from academics (C)</td>
<td>Industry-wide agreement on minimum requirements (C)</td>
<td>Joint road map developed with EU commission (C)</td>
</tr>
<tr>
<td>Case B (actual strategy)</td>
<td>Joint effort among competitors and public authorities (C)</td>
<td>Loose industry platform (C)</td>
<td>Industry-wide collaboration aimed at exclusion of fake firms (C)</td>
<td>Waste reduction argument used by multiple firms (C+I)</td>
</tr>
<tr>
<td>Case C (actual strategy)</td>
<td>Firm individual R&amp;D (I)</td>
<td>Broad discussions (e.g. conferences) (C)</td>
<td>Common understanding of basic standards within industry (C)</td>
<td>Tests conducted for public authorities (C+I)</td>
</tr>
<tr>
<td>Case D (actual strategy)</td>
<td>Individual dialogues (e.g. with scientific community)</td>
<td>Standard for firm-specific product (I)</td>
<td>Individual attempt to educate about risks (I)</td>
<td>Individual effort to advocate in various EU countries (I)</td>
</tr>
</tbody>
</table>

Notes: C stands for collective practice together with horizontal industry partners or vertical value chain partners. I stands for individual approach by the firm.
<table>
<thead>
<tr>
<th>Practice category</th>
<th>Practice (Main Stakeholders involved)</th>
<th>Most successful strategy based on 4 cases</th>
<th>Exemplary quotes (Case)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop Basic knowledge</td>
<td>Develop technical knowledge (Scientific community, competitors, firms outside of core industry, value chain firms)</td>
<td>C: Share resources for R&amp;D, no differentiation of products yet</td>
<td>• We developed a common understanding of new waste technologies. It is crucial to search joint platforms in areas where the business interests are not overlapping. (B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Initially, we didn’t even have the know-how to understand the technology holistically. […] That is why we discussed within the association with other firms. (A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Since the scientific community strongly participates in the initial knowledge development, public funding can highly impact the knowledge creation. (C)</td>
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<td>• The government initiated and funded the platform for the firms and universities. (A)</td>
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<tr>
<td>Accumulate funding support from stakeholders (Local and national governments, public authorities)</td>
<td></td>
<td>C: Gain scale to get financial support for basic research</td>
<td>• When we developed first ideas, we try to evaluate the social and regulatory consequences we might face. (B)</td>
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<td></td>
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<td>• Do we have a product which strongly affects the end consumer? Do we have a B2B product only? For the first case we need to consider the public reaction and for the second case we need to think about exposure scenarios (not case-specific).</td>
<td></td>
</tr>
<tr>
<td>Evaluate future risks and opportunities (End consumers, NGO, industry associations)</td>
<td></td>
<td>C: Comprehensive evaluation for basic technology</td>
<td>• There are stakeholders such as the scientific community which are interested in the success of an innovation and others such as NGOs which might not be interested. (C)</td>
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<td></td>
<td>• A stakeholder with a positive attitude towards the innovation must not necessarily be the most relevant one, but surely the one easier to get into a constructive dialogue. (D)</td>
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</tr>
<tr>
<td>Exchange and refine knowledge</td>
<td>Identify stakeholders for knowledge exchange (Value chain firms, industry association, competitors)</td>
<td>C + I: Consider stakeholder relevant to basic technology and own firm</td>
<td>• We conducted an eco-efficiency analysis for the agriculture very early. We used the results to inform stakeholders in Berlin, where we invited two environmental NGOs to a dialogue. (B)</td>
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<td>• We typically discuss the need for the technology on a sort of global level with agricultural stakeholders and the broader society. There are a lot of misconceptions in those debates, I think. The stakeholders would always couple those misconceptions with specific examples of what we [Gamma] were doing. And in the course of those discussions you would, for example, realize that people did not know what a gene was. (D)</td>
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</tr>
<tr>
<td>Inform and educate target stakeholders (Local and national governments, public authorities, NGO, industry associations)</td>
<td></td>
<td>C: Share resources among firms to inform stakeholders</td>
<td>• When Firm A says which data it needs in order to get the regulatory admission later on, we would generate these data early in the innovation process to save time later on. (D)</td>
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<td>• If we would have known in the early 90s that the requirements of our product also affect the firms later in the value chain, we would have had addressed the consequences earlier […] to avoid the issues later. (B)</td>
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</tr>
<tr>
<td>Understand stakeholder demands (Value chain firms, industry association, Local and national governments, NGO)</td>
<td></td>
<td>C: Know the requirement for basic technology and specific knowledge for superior products</td>
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</tbody>
</table>
| Setting up key stakeholder relationships                                         |                                                                                                        | C + I: Set up networks on industry and                                                                     | • If you engage in certain discussions early, you can set up relationships with crucial stakeholders very well since they recognize you as someone doing the spadework. (B)                           | 201
Define industry standard
(Local and national governments, public authorities, NGO)

C: Agree on the firm-specific level for later stages

- When we defined the standard, we provided all our know-how at that time. In parallel, we built good relationships with the farmers in different regions. These farmers do not only rely on an ISO stamp later on, […] but on reputation. (B)

- Despite being competitors, our firms collaborated in order to set certain standards. These standards can also exclude certain firms in the future. (C)

- We wanted to create a reputable market for our product. It makes sense to create this market together with other firms taking this innovation seriously. (B)

Organize industry participants
(Competitors, firms outside of core industry, value chain firms)

C: Develop network to collaborate within industry

- During the implementation of exposure tests for REACH, we organized discussions for all firms along the value chain from the material producer to the application manufacturer. (C)

- The platform for electric mobility was a coalition of the willing among politics, industry, and the scientific community. It has an independent executive director. He has industry experience, but was not on the payroll of any firm. (A)

Set common standards
(Competitors, firms outside of core industry, value chain firms)

C: Agree on minimum standards for future products

- Firms collaborated to develop the technical roadmap, which was later even implemented in the regulatory framework of the EU. (A)

- The European Chemicals Agency called the whole industry to agree on exposure criteria. Large firms and experts then developed a categorization system for different scenarios. (C)

Notes: C stands for collective and I for individual practices.

Table A.3. Strategic stakeholder management practices in the medium innovation phase

<table>
<thead>
<tr>
<th>Practice category</th>
<th>Practice (Main Stakeholders involved)</th>
<th>Most successful strategy based on 4 cases</th>
<th>Exemplary quotes (Case)</th>
</tr>
</thead>
</table>
| Generate public acceptance | Inform and educate broader public (broader public) | C + I: Inform about technology with other firms and position own product | • We created the nanotechnology forum to educate the broader public. If you don’t educate the public about those technical innovations, they won’t understand the benefits. (C)  
• A major learning from the GMO case was that we need to provide information to make the technology transparent to everyone. (D)  
• It helps to get support from stakeholders of the same class (as the one against us). There are for instance NGOs with positive attitudes towards our technology supporting us. (B)  
• We provided the information to association X beforehand. They liked the information advantage and supported us. (B) |
| Get third-party endorsement (Scientific community, local and national government, public authorities, NGO) | C + I: Get third-party support for technology and own product specifics | • The individual delegate always follows the opinion of his election district. In the GMO case, for instance, the delegates were personally supporting our technology, but the regional acceptance within their district was non-existent. (D)  
• We learned that it is important to convince the local public and show them local benefits, which we didn’t do that during the field experiments of GMO. (D) |
<p>| Promote technology region specifically (Local government, public authorities, local public) | C + I: Legitimize technology and product per region | • The perception of the market is different to the perception of the scientific community. We can conduct a lot of tests and... |
| Use right balance between scientific | C + I: Use industry | • |</p>
<table>
<thead>
<tr>
<th>Activity</th>
<th>Context</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>and emotional communication (Media, broader public)</td>
<td>platforms and firm-specific channels</td>
<td>publish good results. However, the composter can still say that our bags contain plastics and that plastics are not acceptable. (B)</td>
</tr>
<tr>
<td>Participate in regulatory discussion</td>
<td>C + I: Share burdens for technology regulations and use own channels for firm-specific interests</td>
<td>- The NGO criticized us on an emotional topic and we answered highly scientific. This was just not the right level of communication. (B)</td>
</tr>
<tr>
<td>Generate and share information (Local and national government, public authorities)</td>
<td>C + I: Share burdens for technology regulations and use own channels for firm-specific information</td>
<td>- We developed a central framework to show the crucial steps towards higher driving range of electric vehicles, which we shared with the EU officials. The EU directly used this framework for later regulations. (A)</td>
</tr>
<tr>
<td>Engage in regular discussions (Local and national government, public authorities)</td>
<td>C + I: Share burdens for technology regulations and use own channels for firm-specific information</td>
<td>- We do many tests in-house and within research projects. We often collaborate with the federal authorities and inform them about the process. (C)</td>
</tr>
<tr>
<td>Get third-party endorsement (Scientific community, industry association)</td>
<td>C + I: Get third-party support for technology and own product specifics</td>
<td>- In the medium phase, we developed our products and presented them in conferences, fairs, and positioned them for the later admission procedure. For that, we were in constant contact with the regulating authorities. (C)</td>
</tr>
<tr>
<td>Conduct advocacy (Local and national government)</td>
<td>C + I: Share burdens for technology regulations and use own channels for firm-specific information</td>
<td>- We worked together with University x, especially Professor x, to re-evaluate the facts. The results were recognized by European Patent Office and the OECD. (C)</td>
</tr>
<tr>
<td>Support new product development (Value chain firms)</td>
<td>I: Get relevant information for the development of own product</td>
<td>- The EFSA of the European Commission is one of the main stakeholders to get the regulatory legitimacy. Hence, we work very close with them. We also worked closely with scientific institutions, which have high influence on the final EU report. (D)</td>
</tr>
<tr>
<td>Receive and process market information (Value chain firms)</td>
<td>I: Get relevant information for the development of own product</td>
<td>- The member states have the final say on the regulation. Hence, we have colleagues dedicated to the political discussion within the member states. (not case-specific)</td>
</tr>
<tr>
<td>Get process knowledge relevant to product development (Value chain firms)</td>
<td>C + I: Understand the processes of firms within value chain</td>
<td>- The debate back then was not public. It was a political debate, in which we positioned our opinion through our advocacy department. (B)</td>
</tr>
<tr>
<td>Set up efficient collaboration across value chain (Value chain firms)</td>
<td>C: improve collaboration within own value chain</td>
<td>- We provided technical information to the secondary stakeholders and received market information in return. It was important to know how the stakeholders see and influences future markets and regulations. (A)</td>
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<td></td>
<td></td>
<td>- In parallel, we also tried to use the stakeholder network for our product. For instance, we frequently talked to the CEO of the composter association, who helped us to understand the future and hence improved our market strategy. (B)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- We do not only get the R&amp;D know how, but also process know how. For instance, we learned how the relevant admission office works. (B)</td>
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<td>- It was important to get to know the production cycle of the value chain players […] and to align our pipeline of products accordingly. (A)</td>
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<td></td>
<td></td>
<td>- In the GMO case, we experienced that the acceptance within the value chain was not always there, or it was there but would then be diminished. (D)</td>
</tr>
</tbody>
</table>
The major problem was the lack of consistent acceptance within the value chain, which makes it difficult to develop and launch a successful product. (C)

Anticipate stakeholder issues and align on value chain position (Value chain firms) C: Consider stakeholder issues comprehensively across value chain

Stakeholder issues can also occur. It would be important to anticipate and prepare for them across the value chain. (B)

We evaluate the NGO systematically to estimate their reaction. We evaluate their importance as well as their attitude towards our innovation. (not case-specific)

Table A.4. Strategic stakeholder management practices in the late innovation phase

<table>
<thead>
<tr>
<th>Practice category</th>
<th>Practice</th>
<th>Most successful strategy based on 4 cases</th>
<th>Exemplary quotes (Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain normative legitimacy</td>
<td>Monitor dynamics of public opinion (Media, broader public)</td>
<td>C: Monitor development industry-wide</td>
<td>• We received signals from public authorities and journalists that there might be some risk issues coming up. Our media monitoring department also confirmed these signals. (C) • After some issues with the stakeholders, we developed an issue table to make sure that we won’t be surprised again by these stakeholders. (C)</td>
</tr>
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<td></td>
<td>Continuously provide product information (Media, broader public)</td>
<td>C + I: Provide information cohesively as one industry</td>
<td>• One of our practices to manage the issue was to update our risk study, which we conducted with a review panel consisting of scientists from universities and from the composting institute. The final report will then be written by these third-party reviewers. We transparently published the results. (B) • We had the admission, but admission was not enough. We delivered more information on how we improved the product so that it has no negative effects. (D)</td>
</tr>
<tr>
<td></td>
<td>Set up channels and platforms to respond quickly to stakeholder issues (Industry association, value chain firms, competitors)</td>
<td>C: Share resources and create scale to defend technology</td>
<td>• I am engaged in a competence center (association) for Li-Ion batteries. The network within this association is so strong and so broad (including OEM, cell and battery manufacturers) that we can react quickly and decisively on stakeholder issues. (A) • Recently, we initiated an association to collect data and arguments to advocate for biodegradable bags. (B)</td>
</tr>
<tr>
<td>Maintain regulatory legitimacy</td>
<td>Monitor dynamics of political opinions (Local and national government)</td>
<td>C + I: Monitor development industry-wide and comprehensively across regions</td>
<td>• It looked uncomplicated for a long time. But then, we received information through our network that some people from the federal government might want to prevent our innovation. (B) • We have built a very good relationship with the regulating authorities over the years. We always inform each other about possible issues before they actually happen. (not case-specific)</td>
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<td></td>
<td>React as one industry to issues (Industry association, value chain firms, competitors)</td>
<td>C: Defend technology cohesively as one industry</td>
<td>• At the last second, we managed to prevent the regulation with a joint effort (among many firms). (B) • We conducted tests to show the harmlessness of the product. But you should not do that alone. We had many acid producers working together with us. (C)</td>
</tr>
<tr>
<td></td>
<td>Share burdens and coordinate with other industry participants (Industry association, value)</td>
<td>C: Share resources and create scale to defend technology</td>
<td>• Every third day, we updated our excel table, which we (employees from various firms) used to coordinate the respective efforts we made to discuss with the authorities. (B) • If the issue is on an EU level, I would coordinate my actions with our industry association. The association then coordinates the firms within each EU member state. (not case-specific)</td>
</tr>
<tr>
<td>Support product launch</td>
<td>Accelerate product admission (Public authorities)</td>
<td>I: Use networks and data created in earlier phases to accelerate admission for firm-specific product</td>
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<td>▪ We conducted tests in this region years ago. Now, this was also the first region in which we get the product admission. (B)</td>
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<td></td>
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<td>▪ When we conducted the tests in the earlier phase, we used substances of our product. We could use the generated data later in the admission process. (C)</td>
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<tr>
<td>Ensure adequate launch communication (Broader public, media, NGO, industry associations, Value chain firms)</td>
<td>I: Understand stakeholders’ reactions at launch and choose adequate promotional claims</td>
<td>▪ Two things are important. One has to make the right claims in the promotions and one has to get the support from stakeholders along the value chain. (not case-specific)</td>
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<td>▪ From the biodegradable case we learned that we need find out what message we can write on the bag so that we can communicate the benefit in the adequate way. (B)</td>
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</tbody>
</table>

Notes: C stands for collective and I for individual practices.
References


Annex II – Curriculum Vitae
CURRICULUM VITAE – GENG WU

PERSONAL DATA

Geng Wu
Bavariastr. 16c
80336 München
Germany
Date of birth: October 20th, 1985
Marital status: Single
Nationality: Germany
Phone: +49 175 318 9190
Email: gengwu87@googlemail.com; geng_wu@mckinsey.com

EDUCATION

Since 02/2013 ETH Zurich, Zurich, Switzerland
PhD student at the Department for Management, Technology and Economics

09/2009 – 03/2011 University of St. Gallen, St. Gallen, Switzerland
Degree: Master of Arts (M.A. HSG) in Strategy and International Management

10/2005 – 04/2009 Catholic University of Eichstaett-Ingolstadt, Ingolstadt, Germany
Degree: Bachelor of Science (B.Sc.)

08/2007 – 01/2008 Sun Yat-Sen University, Guangzhou, China
Exchange semester

09/1999 – 05/2005 Gymnasium Wilhelm-Raabe-Schule, Lueneburg, Germany
Degree: Abitur (A level)

EMPLOYMENT HISTORY

Since 12/2011 McKinsey & Company, Munich, Germany
Fellow Senior Associate (senior consultant); currently on sabbatical to accomplish the PhD degree

Fellow (Business Analyst)

Fellow Intern (intern)

06/2010 – 08/2010 Procter & Gamble, Geneva, Switzerland
Intern (Assistant Brand Manager)

02/2010 – 05/2010 University of St. Gallen, St. Gallen, Switzerland
Scientific assistant at the Institute for Customer Insight

05/2009 – 08/2009 Batten & Company (former BBDO Consulting), Munich, Germany
Visiting Associate (intern)

11/2008 – 02/2009  Catholic University of Eichstaett-Ingolstadt, Ingolstadt, Germany
Scientific assistant at the chair of Service Management

08/2008 – 11/2008  Red Sprites Consulting, Berlin, Germany
Visiting Associate (intern)

01/2008 – 06/2008  Robert Bosch Automotive Products, Changsha, China
Intern (Purchasing and Logistics)

AWARDS AND RECOGNITION

09/2011  REHAU Preis Wirtschaft – sole nomination by the University of St. Gallen
for one of the best master theses in Switzerland of my year

Management competition with over 2.700 participants

LANGUAGE PROFICIENCIES

<table>
<thead>
<tr>
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<th>Proficiency</th>
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<tbody>
<tr>
<td>German</td>
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<tr>
<td>Chinese</td>
<td>Native</td>
</tr>
<tr>
<td>English</td>
<td>Excellent</td>
</tr>
<tr>
<td>French</td>
<td>Basic knowledge</td>
</tr>
<tr>
<td>Spanish</td>
<td>Basic knowledge</td>
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