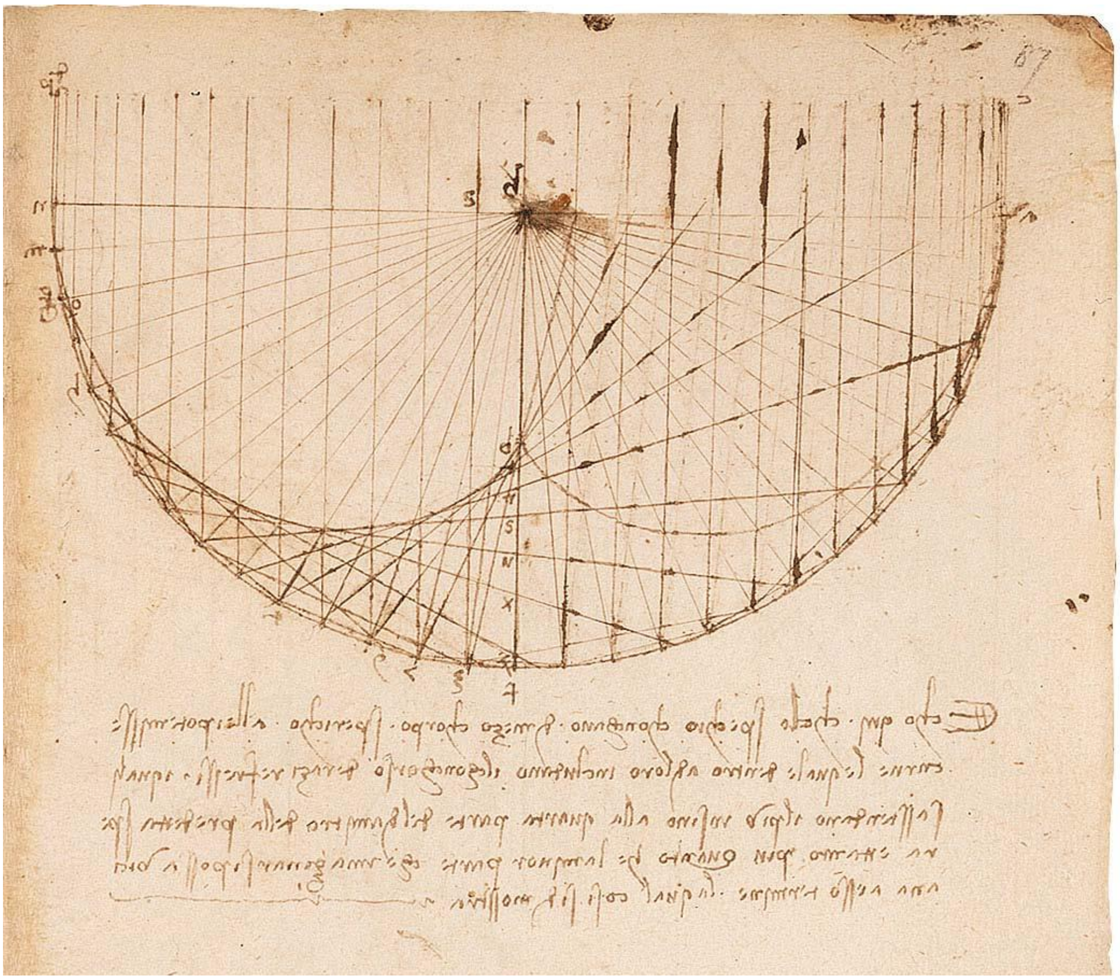
Knowledge Management Strategies for Radical Environmental Innovations

An exploratory analysis of small- and medium-sized manufacturers in the US



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Explanation cover page
Apart from his admirable artistic skills, Leonardo da Vinci was very much ahead of his time. Being a godfather of ideas as the 'perpetuum mobile' and aircraft, he also thought of a way of harnessing solar energy: true radical and environmental innovator. Quite tragically, however, Da Vinci used to write in a coded script to prevent his ideas from spreading. This thesis shows the importance of knowledge sharing for radical innovations. Would we have had solar energy centuries ago, in case Da Vinci had shared his knowledge with other great minds? (Image adopted from www.bl.uk)

Abstract

In response to climate change, manufacturers need to reduce their environmental impacts through actively developing environmental innovations (EIs). In contrast to incremental EIs, radical EIs are more effective to reduce environmental impacts, but simultaneously, their development involves more uncertainty. Additionally, small- and medium-sized manufacturers have relatively less resources to innovate compared to larger firms, making them more dependent on external knowledge. This research aims to provide recommendations to manufacturers and public policy-makers to enhance an overall increase of radical EI adoption. Through the theory of Relative Absorptive Capacity, it explores knowledge management strategies preceding incremental and radical EIs. It does so by a cross-case study of small- and medium-sized manufacturers in the US. In total, 11 interviews gathered data of manufacturers' external knowledge sourcing strategies, organizational structure, and innovation radicalness.

The results show that supplier interactions for radical EIs are more intensive and newer relations compared to incremental EIs. Intensive supplier interactions are even a necessary condition for successful development of radical EIs. Customer interactions do not relate to EI radicalness, but rather to innovation type. Competitor interactions are potentially very fruitful for incremental EI adoption. For radical EIs, competitor interaction is totally absent, due to the newness of innovation. Finally, advisory interaction (e.g. consultants, universities), is not necessarily affecting EI radicalness. Whether a manufacturer sources knowledge from advisories depends on the firm's intellectual capabilities and size.

Firms with a high transformative learning capacity are characterized by an organizational structure in which knowledge disseminates smoothly across different departments. The results show this is necessary for the successful adoption of EIs with higher levels of knowledge complexity. Radical EIs are more likely to be more complex and therefore it can be concluded that transformative learning - although not a necessary condition - is beneficial for the adoption of radical EIs.

The more intensive a knowledge interaction is, the more important strategic fit becomes. Developing radical EIs is more uncertain and requires intensive interactions. Therefore, strategic fit is more important in radical EIs. Strategic fit does not drive effectiveness of adoption, but rather the efficiency.

Radical EIs can be *indirectly* driven by regulatory bodies, whereas incremental EIs are more likely to be result from *direct* governmental actions. Apart from governmental drivers, financial reasons seem to be the most influential in adopting an EI.

Acknowledgements

I am pleased to show you the end product of six months' work. The research process was at times challenging and like an adventure, too. A challenge and adventure that I have enjoyed and learned from, both professionally and personally, but also one that I could not have done by myself.

Moving back to my parents' in January, the first months of February and March were characterized by a lot of passive research activities in the library: from identifying the research problem to building a theoretical perspective. I am especially grateful to Mendel Giezen for his feedbacks, especially in this crucial first phase. I have always enjoyed the conversations, both formal and informal and I am looking forward to working with you in the near future. Regarding the first months, I would also like to say a big 'thank you' to my parents who not only facilitated housing, but also never failed to express their love and trust in me.

The real adventure started in March, when I flew to Boston. Here I started an internship at RenewThink, a sustainability management consultant. I would like to thank Arend de Jong for his support in finding my way in Boston, for showing me the insides of entrepreneurial America and for being a mentor on the professional side of life. I wish him all the best in developing RenewThink to a next level and I am sure our paths will cross in the future. Secondly, I wish to thank the interviewees for their valuable time and elaborate answers to my questions. Finally, I would also like to thank my friends in Toronto and Somerville, who made my stay unforgettable. Especially Kendra and Yasi: thank you for giving my life an extra purpose and I hope to see you soon.

Getting back from Boston in June made me realize how much work remained to be done. I would like to thank Mark for joining me at the Amsterdam public library even during hot summer days and Jeffrey (for his library account), and obviously my roommates for putting up with me in those solitary weeks.

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List of acronyms

AC	Absorptive capacity
ASC	American Surgical Company
CoC	Chamber of Commerce
CP	Colonial Printing
CSR	Corporate social responsibility
DK	Draper Knitting
EI	Environmental innovation
EPA	Environmental Protection Agency
ESCO	Energy Service Company
FDA	Food and Drug Administration
HUV	Hybrid-ultraviolet
ILT	International Light Technologies
IMS	Innovative Mold Solutions
IP	Intellectual property
J&J	Johnson and Johnson
KBV	Knowledge-based view
KI	Knowledge interaction
KM	Knowledge management
LED	Light-emitting diode
NPD	New product development
OECD	Organization for Economic Co-operation and Development
PLA	Polylactic acid
PP	Polypropylene
QCA	Qualitative comparative analysis
R&D	Research and development
SFBC	San Francisco Bay Coffee company
SME	Small- to medium-sized enterprise
US	United States
VP	Vice-president

Chapter 1. Introduction

"Anybody is a genius at some point in their lives. Einstein is a genius in one thing, in his expertise. Also Van Gogh. But if you put a bunch of people in the same expertise, you've got a lot of geniuses. That is ***collective genius****. Then you get the innovation, that's when you go there and go brainstorm. That's how we got the machine to an ultimate design."*

Michael Alouane, Director of Quality at American Surgical Company, May 12, 2015.

1.1 Background of the research and problem description

The introduction of the concept of sustainable development in the late 1980s has increasingly encouraged firms to integrate environmental performance into their corporate social responsibility (CSR) strategies (Young & Tilley, 2006). Although these strategies *seem* to be a prerogative of only large firms, it has indeed been found that larger firms are more likely to "address environmental management [...] and reporting strategies" and are undertaking more formal CSR strategies in comparison to small- and medium-sized enterprises (SMEs) (Perrini, Russo, & Tencati, 2007, p.296). It can be argued that this is logical, because on average their environmental pressure is higher, and SMEs are subject to various challenges such as a lack of expertise and capital (Collins, Lawrence, Pavlovich, & Ryan, 2007).

It is generally contended that the manufacturing industries have significantly larger environmental impacts compared to the service sector (Rosenblum, Horvath, & Hendrickson, 2000). Hence, manufacturers are of central concern in this study. For manufacturers, an effective way to improve environmental performance is to adopt environmental innovations (EIs). An EI is defined as a "process which develops new ideas, behavior, products, processes [...] which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets" (Rennings, 2000, p. 322). It is different from conventional, non-environmental, innovation in the sense that it produces environmental benefits and the fact that there is more uncertainty involved (Jaffe, Newell, & Stavins, 2005; De Marchi, 2012; Dean, 2013).

Innovations, be them with or without environmental benefits, can be distinguished based on radicalness. Incremental innovations are step-by-step improvements reflecting "minor changes of existing technologies in terms of design and function" and build on existing knowledge bases and technical trajectories (Kim, Kumar, & Kumar, 2012, p.297). Radical innovations are more disruptive (Carrillo-Hermosilla, Del Río, & Könnölä, 2010) and depart to a greater extent from existing operations (Henderson & Clark, 1990; McDermott & O'Connor, 2002). In the context of EI, incremental innovations are narrowly associated with eco-efficiency, an industrial design concept that is defined as "adding maximum value with minimum resource use and minimum pollution" (Huesemann, 2001, p.21). Eco-efficiency measures are effective in reducing environmental impacts ("using less, polluting less") and are definitely a step in the right direction. However, it is argued that "the external climatic and ecosystem conditions require that companies go beyond incremental to radical innovation" (Szekely & Strebel, 2013, p.477), because eco-efficiency gains provide no "long-term solution to the environmental problems that challenge humankind" (Young & Tilley, 2006, p.404). Consider for example the automobile industry. Fuel efficiency of cars has improved a lot over the last decades, but the environmental impacts are still negative in an absolute sense. Additionally, Hellström (2007) argues that incremental EIs tend to lock-in social practices and enhance a certain path dependency which, as time passes by, becomes more costly to break out of. Radical EIs are also needed for technological development to continue, as any "industry will face decreasing marginal returns on its incremental eco-efficiency efforts, in terms of sustainability and financial improvements, and that it is therefore pertinent to regularly generate radical eco-innovation" (Hellström, 2007, p.150).

For manufacturers to successfully adopt radical EIs, an innovative strategy is required, as well as a strong environmental policy (Geffen & Rothenberg, 2000). But even more importantly, the organization's internal knowledge base and absorptive capacity are important (Cohen & Levinthal, 1990). In order to adopt EIs, firms often have to go beyond their core competences (Teece, Pisano, & Shuen, 1997). Therefore, and especially in the case of smaller firms - who tend to have a smaller internal knowledge base - external knowledge has to be sourced or acquired elsewhere. In a world that is getting more and more globalized, networking and collaboration are increasingly important, a trend that is also reflected in the innovation literature (e.g. Albornoz, Cole, Elliott, & Ercolani, 2014; Brunswicker & Vanhaverbeke, 2014; Higgins & Yarahmadi, 2014)). SMEs collaborate with various knowledge sources such as supply chain partners (suppliers, customers), other market actors (competitors), research organizations (universities, consultants), and regulatory bodies (Hansen, Søndergård, & Meredith, 2002). Horbach, Oltra and Belin (2013) argue that the adoption of EIs requires more knowledge inputs and from more heterogeneous sources, compared to non-EIs. However, it remains uncertain how knowledge management practices of radical innovators differ from their incremental counterparts.

Problem description

Manufacturing firms need to go beyond incremental EIs in order to respond adequately to the degrading climatic conditions (Szekely & Strebel, 2014). Radical EIs are a necessity to maintain economic and sustainable development, but the task seems very challenging, as very little radical EIs adopted successfully (Hellström, 2007). Additionally, smaller-sized manufacturers lack intellectual resources to engage in radical EIs. Where McDermott and Colarelli O'Connor (2002) argue that radical innovation management is very different from that of incremental innovation, Mlecnik (2013, p.104) contends that radical innovations "require high levels of learning and communication", compared to incremental innovations. At the same time, EIs are characterized by higher levels of uncertainty than their incremental and non-environmental counterparts. Knowledge management is thus a critical factor in the development of radical EIs, especially for SMEs.

The development of innovations is an interactive process in which knowledge is passed on from teacher to student firms. To develop or adopt EIs, small- and medium-sized manufacturers are actively collaborating with different supply chain partners (e.g. Seuring & Müller, 2008), as well as with other external organizations. The effects of this have already proven successful (e.g. Albino, Dangelico, & Pontrandolfo, 2012; De Marchi & Grandinetti, 2013; Higgins & Yarahmadi, 2014). Nevertheless, there is no knowledge on how the adoption processes of incremental and radical EIs compare, and which knowledge management strategies manufacturers should apply to adopt radical EIs.

1.2 Theoretical background and knowledge gap

This research applies a knowledge management perspective on innovation processes. Any innovation that is developed or adopted is usually a product of an interactive process between a focal firm and external organizations that provide knowledge, or *knowledge sources* (Caloghirou, Kastelli, & Tsakanikas, 2004; Tödtling & Grillitsch, 2014; Tödtling, Lehner, & Kaufmann, 2009a). Especially for small- and medium-sized enterprises (SMEs) internal development of such knowledge may be costly and inefficient (Collins *et al.*, 2007), which increases the likelihood for external knowledge sourcing (Brunswicker & Vanhaverbeke, 2014; Li & Tang, 2010; Tödtling, Asheim, & Boschma, 2013). Theoretical strands such as (inter-)organizational learning (Fang, Chou, Yang, & Ou, 2012; Larsson, Bengtsson, Henriksson, & Sparks, 1998), network theories (Chiffoleau, 2005; Higgins & Yarahmadi, 2014) and the Open Innovation approach (Brunswicker & Vanhaverbeke, 2014; Pedrosa, Vaelling, & Boyd, 2013) acknowledge the importance of knowledge in the innovation process. Within these strands, the theory of absorptive capacity (AC) is useful to explain innovation adoption processes. It is a bridging concept between organizational learning and innovation adoption, and refers to the extent to which an organization is able to *understand and recognize* external knowledge as valuable, subsequently *assimilate* this knowledge, as well as finally *apply* it to the internal operations (Cohen & Levinthal, 1990; Lane, Koka, & Pathak, 2006). More specifically of interest is the concept of *relative* absorptive capacity, which views innovation as a product from a bilateral teacher-student relationship, that is a sequence of *exploratory learning*, *transformative learning* and, finally, *exploitative learning* (Lane & Lubatkin, 1998; Valentim, Lisboa, & Franco, 2015). Relative AC is a suitable concept to study the various inter-organizational relationships of manufacturers. It is expected that different knowledge sources provide different knowledge types, have different roles and functions in the process, and interact differently with the innovating firm (Grillitsch, Tödtling, & Höglinger, 2015). The concept of (relative) AC is a timely issue as appears from recent studies. A conceptual paper by Robertson, Casali and Jacobson (2012) shows that AC is an appropriate concept to analyze innovation processes. Unfortunately, they only discuss that in the context of incremental process innovations. Ritala & Hurmelinna-Laukkanen (2013) apply relative AC and *do* compare incremental and radical innovations, but have only considered cases of *coopetition* – i.e. interactions between competitors. They found evidence that radical innovations are much harder to develop in coopetition than incremental innovations. Other studies have focused on environmental performance directly, rather than innovation radicalness. For example, Gluch, Gustafsson and Thuvander (2009) use AC to explain green innovation in the construction industry and Ghisetti, Marzucchi and Montresor's study on EIs (2015) focused on knowledge sourcing strategies. Through a quantitative analysis, they found that knowledge sourcing has a positive correlating effect on

EI performance. However, they were unable to explain the intermediate linkages, and it still remains a black box.

Knowledge gap

This research helps to fill at least three knowledge gaps. First, it makes a distinction between radical and incremental EIs. So far, the academic literature has been biased towards incremental eco-efficiency innovations (e.g. Dienes, 2013; Robertson, Casali, & Jacobson, 2012). Therefore, this research will direct the focus away from incremental EIs, and instead towards EIs that are regarded as high potential in the process toward a sustainable society (Hellström, 2007). It has to be admitted that to an extent this bias seems logical, because approximately 90% of all innovations are considered incremental (Rothwell & Gardiner, 1988). But the degrading climatic conditions and the pursuit of technological development ask of manufacturers to actively adopt radical EIs. Nevertheless, academic literature has not directed much attention to how such innovations are developed.

Second, this study gives insights into how manufacturers interact for knowledge during the adoption *process* of EIs. Process is emphasized, because existing literature has already successfully shown a correlation with certain (environmental) *outcomes*. Numerous studies establish the positive influence of external knowledge sources on (environmental) innovation performance (e.g. Albino *et al.*, 2012; De Marchi & Grandinetti, 2013; Delgado, 2011; Wong, 2013). However, it remains unclear how they do so, what their role is in the process, and whether this process differs for radical and incremental EIs.

Third, this research will apply relative AC in an empirical study. Although the concept has been increasingly used in academic papers over the first decade of the 21st century, most studies contain only theoretical or conceptual views (Lichtenthaler, 2008; Martinez, Jaime, & Camacho, 2012). Applying relative AC empirically might reveal weaknesses or points of improvements for further empirical studies.

1.3 Research aim and scope

The research aim is to enhance the adoption of radical environmental innovations by, firstly, providing recommendations to small- and medium-sized manufacturers on their knowledge management strategies based on a comparison of external knowledge interactions (KIs) preceding the adoption of both radical and incremental environmental innovations, and, secondly, by providing recommendations to public policy-makers based on an analysis of governmental interactions with manufacturers as well as the barriers and drivers of EIs.

For one, this research contributes descriptive knowledge of the different innovation processes of both incremental and radical EIs, and two, normative knowledge through recommendations to the manufacturers and public policy-makers on how to enhance the adoption of radical EIs. Although KIs often take place on a personal level, this research will apply a firm-level perspective, as the main application of the resulting insights in KIs is directed at improving manufacturer's external knowledge sourcing strategies.

This study is conducted in combination with an internship at RenewThink, a consultant in business sustainability, based in Lynn, Massachusetts. Therefore, this study is geographically delineated to the US, and more specifically to Eastern Massachusetts. The units of observation are small- to medium-sized manufacturers. This research defines SMEs on the basis of amount of employees, which is 300 full time equivalents at maximum. In this case, the amount of employees is an acceptable indicator, because of the comparison of KIs, a concept that is more accurately correlated with human behavior than, for example, annual turnover rates. Manufacturers are under examination, because their respective environmental pressures are likely to be higher than organizations in the service sector. This in turn increases the likelihood of finding EIs to analyze, and especially radical EIs. Additionally, the existing literature on EI focuses on production methods (e.g. Bartlett & Trifilova, 2010; Bönte & Dienes, 2013), which suits manufacturers well. As knowledge plays an important role, this study is delineated to technological innovations, because it is assumed that these require more KIs than 'softer' organizational innovations (Lefebvre, De Steur, & Gellynck, 2015).

1.4 Research questions

In order to tackle the identified problem and achieve the research aim, the following main research question has to be answered:

How can knowledge management practices enhance the adoption of radical environmental innovations within small- and medium-sized manufacturers in the US?

Four sub-questions are posed and provide necessary building blocks that help answering the main research question.

a. How do external knowledge sourcing practices for radical environmental innovations differ from incremental environmental innovations?
b. How do different external knowledge sources (suppliers, customers, competitors, advisories) play a role in the adoption of radical and incremental environmental innovations?
c. How do internal knowledge management practices relate to radicalness of environmental innovations?
d. What are the perceived barriers and drivers of radical and incremental environmental innovations? And how can governmental actions increase the likelihood of small- and medium-sized manufacturers successfully adopting radical EIs?

1.5 Research framework

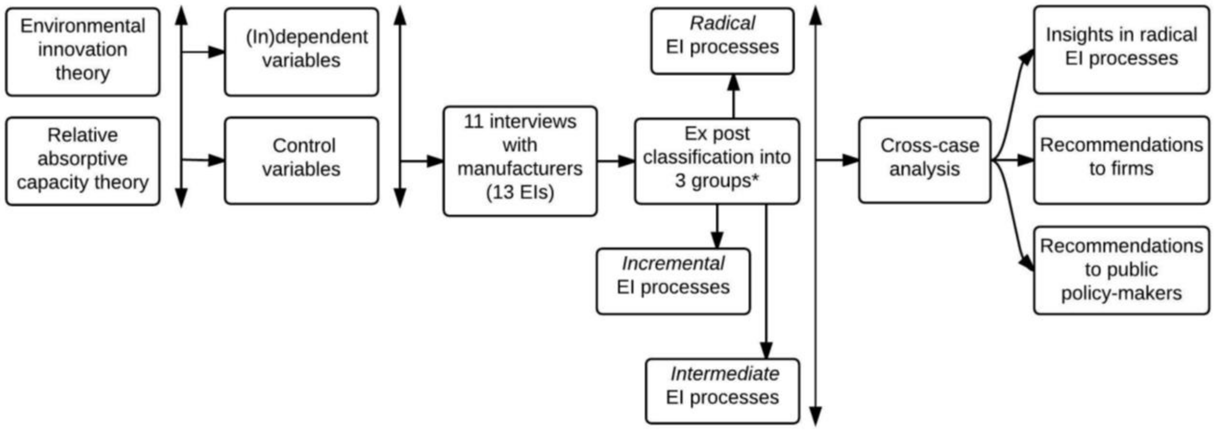

Figure 1: Research framework

In Figure 1, the research framework is presented. In order to achieve the primary and secondary research aims (recommendations to manufacturers and public policy-makers, and insights in radical EI processes), a cross-case analysis will be conducted. This is a qualitative analysis which ultimately compares knowledge management practices of radical with those of incremental EIs. Because radicalness is a scale variable, a group of intermediate EIs is included. The classification of the groups is done after the radicalness of each innovation is assessed, which can only be done after the data (11 semi-structured interviews with managers of small- and medium-sized manufacturers) have been collected and coded through NVivo 10. Desk research has been conducted to better understand the theories of (relative) absorptive capacity, as well as EI. From these theories, the relevant dependent, independent and control variables are identified, which help structuring the data collection method.

1.6 Outline

In *Chapter 2*, theoretical backgrounds of the radicalness of environmental innovations will be laid out. On the basis of conventional innovation theories, environmental innovation research and innovation radicalness, a definition of radical and incremental EI will be constructed. Subsequently, definitions of knowledge interaction and knowledge management will be presented. Finally, the theory of relative absorptive capacity is presented. This is a fitting theoretical concept to assess (external) knowledge management processes and innovation adoption. Altogether, the theoretical considerations facilitate identification of relevant variables and provide an increased understanding of the research subjects, which will enable for further analysis. The analysis is conducted with different research methods, presented in *Chapter 3*. All relevant methodological choices are elaborated upon and include research strategy, method, and data collection strategy. The chapter ends with a reflection on the research quality, providing extra validity and reliability. *Chapter 4* comprises a structural presentation of results, along the different sub-questions. First, a radicalness analysis of the sampled cases will facilitate for a clustering of cases. Second, an overview is presented of all interactions that the manufacturers engage in for EI adoption, which is followed by an in-depth analysis of each of the relations with the respective knowledge sources. Subsequently, an analysis of internal knowledge management for radical EI adoption is presented and, finally, the different barriers and drivers for EI as well as the role of governmental actions herein are presented. *Chapter 5* describes limitations of the research and indicates specific avenues for further research. The second to last chapter - *Chapter 6* - contains conclusions, summarized in a concise and clear way and structured along the respective sub-questions. These answers provide a natural step to the final chapter - *Chapter 7* - in which the recommendations are separately presented for both manufacturers, as well as public policy-makers.

Chapter 2. Theoretical framework

This chapter concerns the theoretical foundations of this research. Firstly, a definition of the dependent variables, radical and incremental environmental innovation, is constructed (Par. 2.1). Subsequently, paragraph 2.2 elaborates on knowledge management and knowledge interactions. These conceptualizations are then used to present the theory of (relative) absorptive capacity (Par. 2.3). Paragraph 2.4 concludes by providing a summary of all presented variables and their relations.

2.1 Radical and incremental environmental innovation

The dependent variables of this research are incremental and radical environmental innovations. In the following paragraphs the general concept of EI will be laid out. Firstly, common academic conceptualizations of EI are presented, as well as the specificities of EI in comparison to conventional innovation (Par. 2.1.1). Subsequently, existing typologies of conventional innovations are provided which include the five classic Schumpeterian types of innovation, as well as the radical and incremental types of innovation (Par. 2.1.2). Finally, these considerations will be synthesized to come to a narrower working definition of radical and incremental EI (Par. 2.1.3).

2.1.1 Environmental innovation

In order to contribute to sustainable development, firms are developing and adopting innovations that enhance their sustainability performance. The academic literature comprises multiple definitions of such innovations, which overlap to a large extent. However, some noteworthy differences are touched upon, in order to clarify the more narrowly defined application of EI.

A report by Little (2005) concerns “sustainability-*driven* innovation”, which is defined as new products, processes or markets that are “driven by social, environmental or sustainability issues” (p.3). Note here the emphasis on the motivation of the innovator, who is triggered for action. Klewitz and Hansen (2014) purposefully coin “sustainability-*oriented* innovation”, emphasizing the direction of innovation, which moves toward a certain sustainability-related goal. In contrast however, the OECD definition of eco-innovation is less stringent regarding the *ex ante* goal or motivation of an innovation, as it comprises any “innovation that results in a reduction of environmental impact, whether such an effect is intended or not” (OECD, 2009, p.13). This is legitimized since it is likely that companies engage in eco-innovations for economic or other reasons not being purely environmental (Arundel & Kemp, 2009). This research will adhere to this latter argument, because it is to be expected that it is very difficult to identify sustainability-driven or -oriented innovations within the specific research sample (small-to medium-sized manufacturers in the US). Also in accordance with the OECD definition, this research excludes social and economic aspects of sustainability and focuses solely on the environmental aspects of innovation, which is called eco-innovation or environmental innovation (EI). Reasons for doing so are the above-average conditions of social and economic sustainability in the US and the perceived urgency of globally increasing greenhouse gas (GHG) emissions. Although their similarity, this research chooses to use the term EI over eco-innovation, as it appears to be more commonly applied in innovation literature (Pinget, Bocquet, & Irege, 2014).

The most renowned definition of EI is termed by Rennings (2000, p.322) as a "process which develops new ideas, behavior, products, processes [...] which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets". However, Rennings' conceptualization – defined in the aftermath of the Kyoto Protocol - can be criticized for being too broad as it leaves space for 'sustainability targets' that are politically defined, rather than framed in absolute physical terms. Moreover, such a definition covers a heterogeneous set of innovations (Horbach *et al.*, 2013), which restricts the possibility of presenting methodologically sound results. For example, it can concern recycling, waste management, eco-design or any other product, process, or organizational innovation that reduces emissions (De Marchi, 2012). With the research goals (amongst others: comparing radical with incremental innovations) in mind, this research will define EI more narrowly. In doing so, it builds on existing types of conventional Schumpeterian innovation and - in more detail - on the radicalness of innovation (paragraph 2.1.2). However, firstly, it is important to give insight on the specificities of EI in comparison with conventional innovation. This is necessary, because the drivers and barriers and outcomes of EI are somewhat different from their conventional counterparts. The differences between conventional and environmental innovations are listed in Table 1.

	Conventional innovation	Environmental innovation	Sources
Externalities	- Knowledge externalities	- Knowledge externalities - Environmental externalities	Jaffe *et al.*, (2005); Dean (2013)
Drivers	-Technology push - Market pull	- Technology push - Market pull - Regulatory push/pull	De Marchi (2012); Higgins & Yarahmadi (2014); Pinget *et al.* (2014)
Barriers	-Economic barriers (costs, risks, customer responsiveness) -Technological barriers -Organizational barriers	-Similar, but barriers are likely to be *higher*, due to more uncertainties	Abdullah *et al.* (2015) ; Madrid-Guijarro *et al.* (2008) ; Pinget *et al.* (2014)
Level of uncertainty	High	High*er*	Bönte & Dienes (2013); De Marchi (2012); De Marchi & Grandinetti (2013)

Table 1: Differences between conventional and environmental innovations.

First, EIs bring about different *externalities* compared to conventional innovations. Externalities occur when a firm or individual conducts an activity that produces side effects that affect an unrelated third party (Buchanan & Stubblebine, 1962). These effects can be positive or negative. Positive externalities provide benefits for the public, whereas negative externalities impose costs on them. The value of these externalities is uneasy to capture (Cohen & Winn, 2007). For instance, patents and licenses help capturing value from intellectual properties, whereas carbon pricing helps capturing the costs of pollution. Any innovation produces knowledge externalities, but what sets EI apart from conventional innovation is that the outcome comprises positive environmental externalities (Jaffe *et al.*, 2005).

Second, the *drivers* of EI are not entirely the same. In theory, EI is driven by the technology push, the market pull and the regulatory push and pull. In contrast, conventional innovation is only driven by the technology push and market pull (De Marchi, 2012; Higgins & Yarahmadi, 2014). Market pull forces stem from the fact that innovation is driven by consumer demand. Consumers generally want products that deliver a service faster, smarter or more efficient. The technology push stems from the supply side and is driven by research and development. The difference between EI and conventional innovation is the role of the government as a driving force. As the environmental state is a common good, the government has a responsibility to prevent or fight pollution. It can regulate market failures by setting standards, by providing incentives through subsidies and by punishing actual violators and deterring potential violators through fines.

Third, regarding the *barriers* to innovation, it is generally distinguished between external and internal barriers (Madrid-Guijarro, Garcia, & Van Auken, 2008; Abdullah, Zailani, Iranmanesh, & Jayaraman, 2015), although here we distinguish between economic, organizational and technological barriers (Pinget *et al.*, 2014). Most important barriers for SMEs to engage in innovations are economic barriers, such as investment costs, a lack of customer demand, or higher risks. Additionally, smaller-sized firms deal with technological barriers, as they might not have the necessary skills and equipment to innovate (Collins *et al.*, 2007). Finally, organizational barriers consist of a lack of strategy and insufficient human resources. These barriers are the same for conventional and environmental innovations, however, for EIs, these barriers might be stronger, which has to do with the higher level of uncertainty.

Fourth, adoption processes of EIs are often characterized by higher levels of *uncertainty* and complexity (Bönte & Dienes, 2013; De Marchi & Grandinetti, 2013) due to the fact that "there are virtually no standards with respect to specific technologies" (Bönte & Dienes, 2013 p.503). The market for environmental products is more uncertain, as well as environmental friendly technologies are newer (Pinget *et al.*, 2014). This directly results in heavier barriers for EIs, especially the technological and economic ones. In their study of EIs in manufacturers, De Marchi & Grandinetti (2013, p.571) argue that EIs have an "intrinsic complexity" that requires more collaboration between network partners, which deliver complementary types of specialist knowledge and competences. Due to higher complexity "cooperation may be even more important than when it comes to introduce other types of innovations" (De Marchi, 2012, p.615). However, the already narrowed down definition of EI (i.e. focus on outcome instead of drive or orientation) is still *so* broad that the difference in uncertainty between conventional and EI is expected to be of minor influence. For example, this study's sample includes EIs that are adopted purely from economic reasons, but do have – minor or major - environmental benefits. Nevertheless, it appears relevant to study the KIs that contribute to the adoption of EIs.

2.1.2 Typologies of conventional innovations

There exist multiple ways to create typologies of innovation. As this research aims to uncover differences between incremental and radical EIs, it is constructed on two ways to distinguish between innovations: the Schumpeterian innovation types and the radicalness of innovation.

Schumpeterian innovation types

The classic division of Schumpeter separates five kinds of innovation, being a new good or product, a new production method, a new market, a new source of supply, and a new organization of industry (Hellström, 2007). This division is generally accepted, but often reduced to process, product, and organizational innovation (e.g. Polder, van Leeuwen, Mohnen, & Raymond, 2010). Process innovations relate to the production process of goods and services, product innovations concern entirely or partly changed products and organizational innovations constitute a "reorganization of routines and structures within the firm" (Klewitz & Hansen, 2014, p.58). As said earlier, a more narrowly constructed definition of EI based on this classic division of innovation types is well-suited, as reflected in the literature (e.g. Bönte & Dienes, 2013; Carrillo-Hermosilla, Del Río, & Könnölä, 2010; Hellström, 2007; Klewitz, Zeyen, & Hansen, 2012).

This research is demarcated to only product and process innovations for two reasons. First, it is important to present methodologically sound results, which is more difficult with a very widely defined dependent variable. Simply excluding organizational and marketing innovations enhances the practical feasibility of the research. Second, technological innovations (i.e. product and process innovations) are expected to result from more complex innovation processes, due to their substantially higher level of uncertainty (Schmidt & Rammer, 2007). This makes studying knowledge management and knowledge interactions more relevant and worthwhile.

Incremental and radical innovation

Another commonly applied method of dividing conventional innovations relates to the newness, or 'radicalness' of an innovation. Especially quantitative studies dichotomize between incremental and radical innovations, loosely based on for example "the assumption that innovations could be categorized as either incremental or radical" (Koberg, Detienne, & Heppard, 2003, p.22). However, innovation radicalness is not that easily determined, as it is a scale variable and a relative concept. Whether an innovation can be seen as incremental or radical depends on how disruptive it is and on the amount of uncertainty involved in the innovation process (McDermott & O'Connor, 2002). Disruption and uncertainty play a role in two domains: the *technology domain*, which regards the internal domain of the firm and the extent to which the existing operations have changed, and, externally, the *market domain*, and to what extent it is affected or disrupted (Herrmann, Gassmann, & Eisert, 2007). The two domains and the two dimensions form the basis of a more valid, aggregate definition of innovation radicalness (see Table 2).

	Domain	Dimension	Scale: Incremental ←→ Radical			Sources
Innovation radicalness	Technology	*Impact*	(-)←	Technological disruption	→(+)	a, b, c, d
		Uncertainty	(-)←	Technological uncertainty	→(+)	a, d, e, f
	Market	*Impact*	(-)←	Market disruption	→(+)	a, c, g
		Uncertainty	(-)←	Market uncertainty	→(+)	a, f, h, i

Table 2: Radicalness of innovation

a) Herrmann et al. (2007)
b) Henderson & Clark (1990)
c) Carrillo-Hermosilla et al. (2010)
d) Ritala &Hurmelinna-Laukkanen (2013)
e) Dewar & Dutton (1986)
f) McDermott & O'Connor (2002)
g) Tushman & Anderson (1986)
h) Colarelli O'Connor (1998)
i) Lettl (2007)

- *Technology domain*

Incremental innovations represent "minor changes and modifications to products and technologies" (Ritala & Hurmelinna-Laukkanen, 2013, p.158). To determine how minor (or major) such a change actually is Henderson and Clark (1990) distinguish between radical and incremental innovations on the basis of the scope of impact, or to which this research refers to as *technological disruption*. In the context of product development, Henderson and Clark make use of the concepts 'component' and 'core design' (or 'system'). In their conceptualization an incremental innovation entails a new product in which the relationships between the components and the system remain unchanged. On the other hand, a radical innovation entails a new product in which the relationship between the components and the overall product system has changed (see Illustrative box 1).

Illustrative box 1: Technological disruption

Henderson and Clark illustrate the difference with a room fan. An incremental innovation would comprise a replacement of a single component (e.g. a more efficient engine or blade), whereas radical innovation could entail an air-conditioning system including totally different components such as refrigerants and compressors. Notice that the function of the fan and air-co is the same, but the relations between the components have drastically changed.

Carrillo-Hermosilla *et al.* (2010) build on the component-system division and increase its validity by adding an intermediate type. In the context of EI, Carrillo-Hermosilla *et al.* (2010) speak of sub-system change, which differs from component innovation in that it comprises more than one component, and thus affects relationships of more than one component.

The second dimension within the internal operations of the firm is the *technological uncertainty* involved in the innovation process. Incremental innovations involve less uncertainty and are less risky to develop (McDermott & O'Connor, 2002). Due to less uncertainty, there is little need for new knowledge to successfully adopt an innovation. In contrast, radical innovations involve larger departures from existing knowledge bases and contain by definition a higher degree of new knowledge (Ritala & Hurmelinna-Laukkanen, 2013). In the context of process innovations, Dewar & Dutton's quantitative study (1986) of manufacturers finds that knowledge depth or technical expertise is more important in the adoption of radical than of incremental innovations. In case such expertise is few or scarce, which is more likely for smaller sized manufacturers, external knowledge becomes more important. Following this logic, incremental innovations are expected to be less reliant on external knowledge than radical innovations. It is difficult to, *ex ante*, quantify or assess the levels of uncertainty involved, but Dewar and Dutton used the amount of internal technical specialists as an indicator of internal knowledge base, which is inversely correlated with uncertainty. Additionally, looking *ex post* at how much learning or training was involved in the innovation process is a good indicator for external knowledge.

- *Market domain*

Technological innovations not only affect a company's internal business, but have external consequences for the market, which is called *market disruption*. External incremental innovations are adoptions of innovations that were already in use or produced by a larger crowd of peers (in this case competing manufacturers). Firms that ultimately adopt incremental innovations are called late adopters or laggards (Lee, 2010). Their effect on the market is not disruptive as they merely follow the market. In contrast however, external radical innovators bring new technologies on the market and are referred to as innovators or early adopters (*ibid.*, 2010). External radical innovations are unique technological products or production technologies that make obsolete their existing alternatives, as they outrun their predecessors on scale, efficiency, or design (Tushman & Anderson, 1986). Carrillo-Hermosilla *et al.* (2010) argue that radical innovations might firstly only be appreciated by a small niche, but after the technology has been improved, might take over the dominant design.

Apart from the degree to which an innovation impacts the market - or society - the radicalness of an innovation can also be determined by the involvement of *market uncertainty* in the innovation process (McDermott & O'Connor, 2002). Just as with technological uncertainty: the more uncertainty involved, the more radical the innovation. In this case the uncertainty, or, the knowledge that the focal firm is lacking, concerns market demand and market receptiveness. Close customer collaboration and marketing skills can reduce the risk of failure (McDermott & O'Connor, 2002). Due to McDermott and O'Connor's focus on product innovations, the relevance of market uncertainty is expected to be less relevant for process innovations, because the end-user is less likely to be affected.

In sum, the extant literature regards conventional incremental innovations as small changes on the component level, built on an existing knowledge base with little uncertainty involved in the adoption process. Radical innovations are changes at the system or sub-system level, require more new knowledge, and have the potential to make obsolete its already existing alternatives.

2.1.3 Radical and incremental environmental innovations

This chapter combines the insights of EI specificities, the conventional Schumpeterian innovation types, and innovation radicalness in order to come to a working definition of radical and incremental EI.

Regarding the EI specificities, two aspects are important to take into consideration. Firstly, EIs are driven by regulatory push and pull factors. Governmental or public authorities play an important role in triggering innovation processes. There is a notable difference that sets governmental authorities aside from market-based or research actors. Namely the fact that governments ultimately have absolute power, rather than business networks which are more likely to be iterative, trust-based, interactive relationships. This affects the way in which firms receive and understand the exchanged information (Hansen *et al.*, 2002).

The second difference between conventional innovations and EIs is the higher level of uncertainty involved. As elaborated above, this overlaps with the conceptualization of innovation radicalness and is therefore automatically included in the final definition of radical and incremental EI. On a side note, however: when assessing radicalness of environmental *process* innovations, market uncertainty seems to play a lesser role due to the inherent differences in goals between process and product innovations. Products need to be sold on the market, whereas new processes are most likely to remain within the firm. Customers are less likely to be involved in the development process, or at least not as directly as they are in the case of product innovations (Lefebvre *et al.*, 2015; Tomlinson & Fai, 2013).

Of the conventional Schumpeterian innovation types, only product and process innovations will be taken into account. This is because product and process innovations - synonymous for technological innovations - generally require more intense and complex knowledge (Schmidt & Rammer, 2007), which increases the likelihood for SMEs to engage in KIs.

It is of utmost importance to control for the innovation type (product or process), as this is a major determinant of which actors are involved in the innovation process. For example, in a quantitative study of SMEs in the food industry, Lefebvre *et al.* (2015) found that market-based actors are significant in the development of new products, whereas for process innovations no external sources had a significant impact. Tomlinson and Fai (2013) conclude similarly, as client cooperation is a stronger predictor for product innovations, whereas supplier collaboration is clearly better at predicting process innovations.

Previous research that applies the EI specificities to technological product and process innovations is conducted by Klewitz, Zeyen, and Hansen (2012) and Wong (2013). Klewitz *et al.* (2012) applied the general Schumpeterian types of innovation (process, product, and organizational) to the environmental dimension. Environmental process innovations reflect an alteration in the production process of goods or services with the outcome of environmental impact reduction. Wong (2013, p.323) defines environmental process innovation as “the use of environmentally friendly technologies and manufacturing processes to produce goods and provide services that impose no or less negative impact on the people and the environment”, whereas an environmental product innovation entails “producing a new product or service that inflicts no or less negative impact on the environment than a conventional or competing product”. Accordingly, Klewitz *et al.* (2012) show that process innovations are commonly used in research in manufacturing industries, which adds to the suitability of this study.

2.2 Knowledge interactions

This research analyzes innovation from the firm perspective and as a result of knowledge flows. The fundamental theory that combines these views is the knowledge-based view (KBV) (Grant, 1996). The KBV considers knowledge as “the most strategic resource of the firm”, which enables the firm to develop competences and capabilities which ultimately improve the firm's performance or competitiveness (Daud, 2012, p.4224). The theory of absorptive capacity, to which we will turn soon, is very closely related to the KBV, but focuses on innovation specifically - rather than performance in general - as the main output. Knowledge is created within the firm by individuals, but also externally by networking with other organizations (Valentim *et al.*, 2015). These networks, or interactions, can be formal – such as operating in strategic alliances, or informal, such as convening at industry trade shows. Figure 2 presents three different networks that SMEs typically engage in: a business network, a regulatory network and a knowledge network (Hansen *et al.*, 2002).

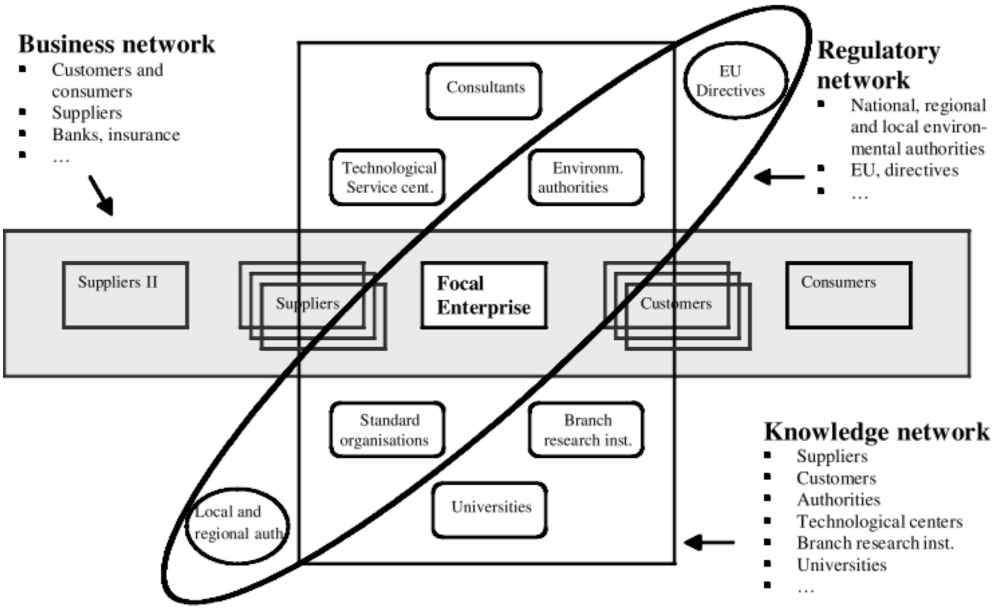

Figure 2: SME networks (adopted from Hansen et al., 2002).

What sets these networks apart is the way in which information is communicated and how a different perspective affects the way in which such information is understood. It is important to be aware of these differences when analyzing knowledge interactions. However, it has to be admitted that none of these networks are mutually exclusive and different organizations can be part of one or more networks simultaneously (*ibid.*, 2002). Consider for example, on the one hand, a business network. This is primarily used to add value to a product or service and organizations deal with forces of competition. On the other hand, a regulatory network is focused on exerting democratic values and policy-making. Regulatory bodies can function as important actors to spur EI by incentivizing environmentally sound, as well as innovative behavior (Horbach, Rammer, & Rennings, 2012). Here, it is agreed with Hansen's acknowledgement of the constitutive differences between business and regulatory networks and thus will be analyzed separately and in combination with the analysis of the perceived drivers and barriers of EI.

As this study aims to compare interactions with different innovation partners - or *knowledge sources* - a brief overview of typical relations is given per source. Firstly, customer interactions are typically useful for the development of new products or services (Tödtling, Lehner, & Kaufmann, 2009). Integrated customer feedbacks increase a firm's marketing capability, and with regard to the adoption of radical innovations - characterized by higher market uncertainty - active user involvement in the adoption process is proven to be beneficial (Lettl, 2007). Secondly, suppliers are also to be found influential in contributing to product innovations (Tödtling *et al.*, 2009) as well as incremental process innovations (Mlecnik, 2013). Thirdly, competitors, and especially in geographical clusters, can spur innovation adoption very efficiently, although competition is a significant barrier to knowledge sharing (Ritala & Hurmelinna-Laukkanen, 2013). Finally, independent research organizations such as universities and consultants have proven to be effective especially in high-tech industries (Tödtling *et al.*, 2009).

Knowledge management practices can be divided into three dimensions, being acquisition, conversion and application (Valentim *et al.*, 2015). *Knowledge acquisition* is the internalization of external knowledge. This can be done by hiring competitor's employees, by market research or direct customer interactions. Acquisition does is not necessarily involve a monetary transaction, as it can also be based on informal relations of friendship. *Knowledge conversion* is the transformation of the internalized knowledge into information that is understood by the employees of the focal firm (Daud, 2012). *Knowledge application* is the use of the transformed knowledge for creating products with market value (Valentim *et al.*, 2015). These three knowledge management strategies show close overlap with the theory of *absorptive capacity*, which is presented over the following paragraphs. In specific *relative* absorptive capacity, which is a knowledge management concept that bridges organizational learning and innovation, with an emphasis on the dyadic relation between a student and teacher organization.

2.3 Relative absorptive capacity

This paragraph presents a brief, but in-depth historical background of the concept of absorptive capacity (AC), and subsequently explains the model of relative absorptive capacity (Par. 2.3.1). Subsequently, more attention is paid to the distinctive learning process of relative AC: exploratory learning (Par. 2.3.2), transformative learning (Par. 2.3.3), and exploitative learning (Par. 2.3.4).

2.3.1 Historical development of absorptive capacity

As this research aims to explore the link between knowledge interactions and innovation radicalness, the theoretical concept of AC is applied. AC is defined as the "ability to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen & Levinthal, 1990, p.128). AC has become popular in academic literature as it connects with theoretical strands of knowledge management, innovation, and (inter-)organizational learning (Schildt, Keil, & Maula, 2012). It has also been used in the context of EI (e.g. Ghisetti *et al.*, 2015; Gluch, Gustafsson, & Thuvander, 2009). Since its establishment, AC has undergone a series of adjustments and developments.

Initially, conceptualized by Cohen and Levinthal (1990), AC was framed quite narrowly and functioned purely as a bridging concept between learning and innovation (Robertson *et al.*, 2012). It is generally contended that a firm's AC is path-dependent and builds on prior knowledge and experiences (Lane, Koka, & Pathak, 2006), but in Cohen and

Levinthal's seminal work, AC was only modeled as research and development (R&D) investment: the higher a firm's R&D expenditures, the better its AC, and subsequently its innovation performance.

Soon after, AC received more attention, which led to different re-conceptualizations, of which Zahra and George's (2002) stands out. In their article, AC was taken to a higher level of abstraction, focusing not only on innovation, but on competitive advantage in general. Furthermore, they eliminated the distinction between external and internal knowledge (Robertson *et al.*, 2012) and instead viewed AC through the broader perspective of dynamic capabilities. Zahra and George's most noteworthy contribution is AC's re-conceptualization into potential and realized AC (see Fig. 3).

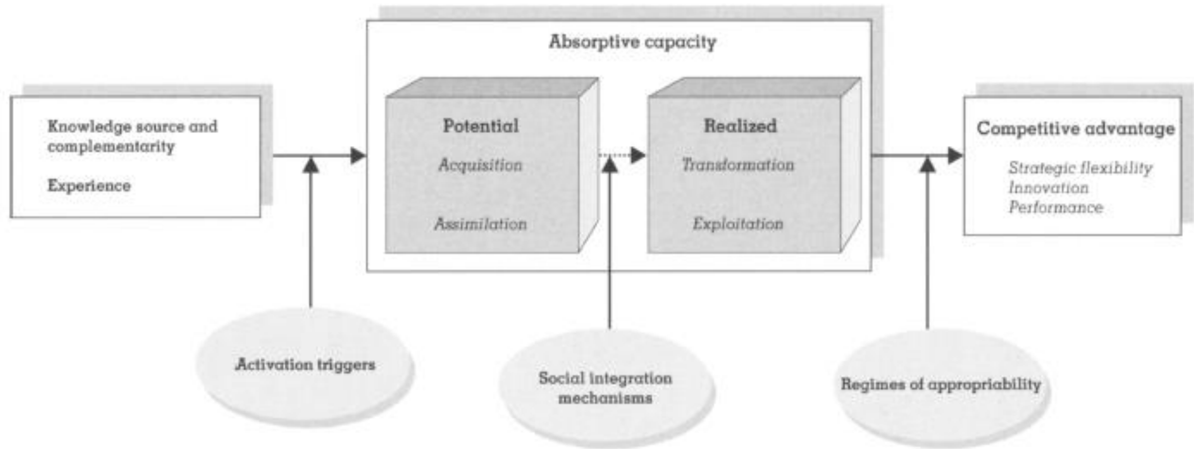

Figure 3: Absorptive capacity conceptualized as two subsets: potential and realized absorptive capacity. Adopted from Zahra and George (2002).

Potential AC comprises acquisition and assimilation of knowledge. It reflects the potential effectiveness of the new knowledge (Ritala & Hurmelinna-Laukkanen, 2013). *Realized AC* comprises transformation and exploitation of knowledge and refers to what is actually done with the new knowledge and to what extent it is applied and exploited (Zahra & George, 2002). It can be viewed as an efficiency concept, framed as a ratio of realized to potential AC (Lane *et al.*, 2006).

However, Zahra and George's broadening of the concept also led to criticism. Lane *et al.* (2006) critically review the AC literature stream. They argue that due to the size and scope of the literature, AC has become "reified" which threatens the validity of studies that have applied it. Therefore, Lane *et al.* rejuvenate the concept somewhat closer to the original definition of Cohen and Levinthal. In contrast to Zahra and George, AC should not be a "pipeline based on efficient knowledge exploitation", but rather function as a "funnel that emphasizes exploratory learning" (Lane *et al.*, 2006, p.855). This research adheres to this line of reasoning as it focuses on the interactions with external knowledge sources, which are more closely related with (external) exploration than (internal) exploitation of knowledge.

In innovation research in general and in AC research in specific, it is important to clarify the applied research perspective. The classic AC definition of Cohen and Levinthal looked at knowledge processes from the firm's perspective. Other usually applied perspectives are the alliance perspective (Mowery, Oxley, & Silverman, 1996) and the even more specific relational view (Dyer & Singh, 1998) or *relative absorptive capacity* (Lane & Lubatkin, 1998), which both apply a dyad-level perspective. This research builds on the latter, because it aims to compare interactions with different innovation partners. Below, a more detailed elaboration of relative AC is presented.

Relative absorptive capacity

Relative AC considers the dyadic relation between on the one hand, a teacher organization, and on the other hand, a student firm which makes it especially suited to study inter-organizational learning. For clarification, the student firm is the focal manufacturing firm and the teacher firm is the external knowledge source. Lane and Lubatkin (1998) established the concept of relative AC as a critique on the suggestion that all external organizations offer equal possibilities to learn. Rather, they argue, this differs depending on characteristics of the other organization and on characteristics of the learning relationship. Relative AC is better capable of explaining variance in inter-organizational learning, due to the higher validity of measure (Lane *et al.*, 2006). Whereas the conventional construct takes R&D investments as a proxy for AC, relative AC is determined by the exchange partner's knowledge similarity and knowledge-processing similarity (Liao, Fei & Chen, 2007).

It is generally contended that relative AC consists of three stages of knowledge management practices: knowledge *acquisition*, *transformation* and *exploitation* (see Fig. 4).

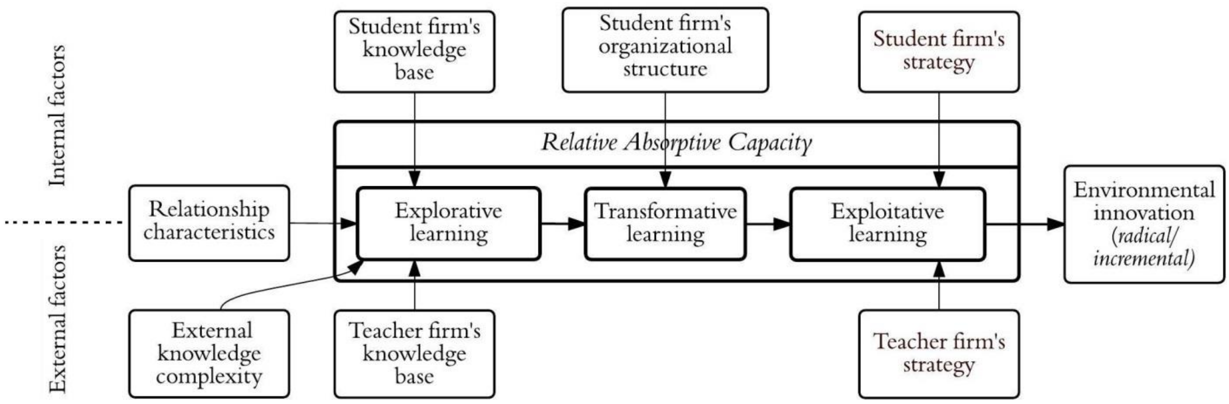

Figure 4: Conceptual framework. Innovation viewed through the lens of a rejuvenated version of Relative Absorptive Capacity. Adopted from 'classic' Absorptive Capacity (Cohen and Levinthal, 1990), Relative Absorptive Capacity (Lane & Lubatkin, 1998) and 'reified' Absorptive Capacity (Lane et al., 2006). Internal firm characteristics are depicted on the upper side of the figure, and external factors on the bottom side.

First, external knowledge is to be valued and recognized, after which it is acquired. This process is called *exploratory learning*. Subsequently, the new knowledge, which is then internalized, has to be assimilated or transformed in order for it to be applied for innovation purposes. It is the transfer or dissemination of knowledge within the firm to the different departments. This process is called *transformative learning* (Lane *et al.*, 2006). Thirdly, the transformed knowledge is applied to 'commercial ends', in this case the adoption of EI, and is referred to as *exploitative learning* (Cohen & Levinthal, 1990; Lane & Lubatkin, 1998; Lane *et al.*, 2006; Zahra & George, 2002).

Whereas the seminal work on AC has already been conducted 25 years ago, AC nowadays is still a relatively hot topic. Due to two recent developments, this research will *not* adopt the relative AC concept as it was presented in the late 1990s, but adheres to a *rejuvenated* version.

First, there is more academic attention for the hitherto neglected, but important variable of the model, being organizational mechanisms (e.g. Cruz-González, López-Sáez, & Navas-López, 2015; Foss, Laursen, & Pedersen, 2011). Such research aims to explain how internal organizational structure (including degree of hierarchy, communication channels, and reward systems) affects the application of new knowledge. Rejuvenated relative AC emphasizes on the one hand a dyad-level perspective of a teacher and student firm, but on the other hand, also sees AC as "move[d] away from a structural perspective to a view of it as more of a dynamic capability" (Lane *et al.*, 2006, p.857).

Second, also in contrast with earlier work (e.g. Lane *et al.*, 2006), more recent contributions have investigated not only AC's predictors, but also its very nature (Zhou & Li, 2012) and effects (e.g. Tzokas, Kim, Akbar, & Al-Dajani, 2015). This research fits today's academic interest as it also focuses both on AC outcomes (in casu: radicalness) and on the manufacturer's internal organizational structure.

In recapitulation, this research will adhere to a modern, modified version of the original relative AC of the late 1990s for three reasons. Firstly, because it is used to explain innovation on the basis of internal knowledge processing from different external sources. Secondly, because of its emphasis on knowledge exploration instead of exploitation. And thirdly, to take into account recent developments around relative AC which is nowadays to be seen as a dynamic capability of the firm. The model as presented in Figure 4 will be outlined in more detail below, with a special focus on how external knowledge sources influence a firm's AC.

2.3.2 Exploratory learning

External knowledge will only be internalized if the firm is able to recognize and understand that knowledge (Lane & Lubatkin, 1998). Acquisition is defined as the "capability to identify and acquire externally generated knowledge that is critical to [its] operations" (Zahra & George, 2002, p.189). The learning mechanism at play is exploratory learning. To visualize this, one can think of a funnel "that allows the firm to search broadly for knowledge that can help meet its specific needs" (Lane *et al.*, 2006, p.855). The breadth or scope of the funnel, and thus the knowledge transfer in the acquisition process, is dependent on *cognitive proximity*, (Lane *et al.*, 2006; Nooteboom, Van Haverbeke, Duysters, Gilsing, & van den Oord, 2007), *external knowledge complexity* (Chen, 2004; Lane *et al.*, 2006), and *relationship characteristics* (Chen, 2004; Tödtling *et al.*, 2009). Other notable influential factors are the presence of certain *activation triggers* (Gluch *et al.*, 2009; Zahra & George, 2002). Below, a concise elaboration on the influential variables of exploratory learning is presented, starting with cognitive proximity, which concerns the relationship between the knowledge bases of the student and the teacher firm.

Cognitive proximity

A firm can only assess external new knowledge as critical, if the firm's *prior scientific* or *technological knowledge* is 'basic' to the new knowledge. Basic knowledge is defined as a "general understanding of the traditions and techniques upon which a discipline is based" (Lane & Lubatkin, 1998, p.464). In case the external knowledge is too different from internal knowledge, the firm will not be able to recognize its value in the first place. Innovation partners must have some *cognitive proximity* to understand one another, which means that "people sharing the same knowledge base and expertise may learn from each other" and is "a matter of speed and efficiency of the acquisition of information, but also, and even more so, of extending the scope of cognition" (Boschma, 2005, p.64). The larger the internal knowledge base, the more exploratory learning can take place. On the other hand, in order to be innovative, the external knowledge needs to be different enough in order to be worthwhile transferring. In a later work (Nooteboom *et al.*, 2007), this is referred to as cognitive distance (see Fig. 5). An optimal cognitive distance is the point where partners have a sufficient mutual understanding, or basic knowledge, but also a sufficiently large cognitive distance in order to exchange novel information.

Illustrative box 2: Cognitive proximity

Consider the material engineers of a plastics molding company that exclusively sells plastics based on polypropylene (PP). The company (i.e. the material engineers) has basic knowledge of material engineering. But, say, the company wants to convert to biodegradable plastics, for which they need to switch from PP to polylactic acid (PLA) as a raw material. Because the material knowledge of the engineers is basic enough to understand that there are differences between PP and PLA, they are able to recognize the external knowledge as valuable, although they might not have knowledge on how to work with PLA. Thus, there has to be some level of understanding for acquisition to take place.

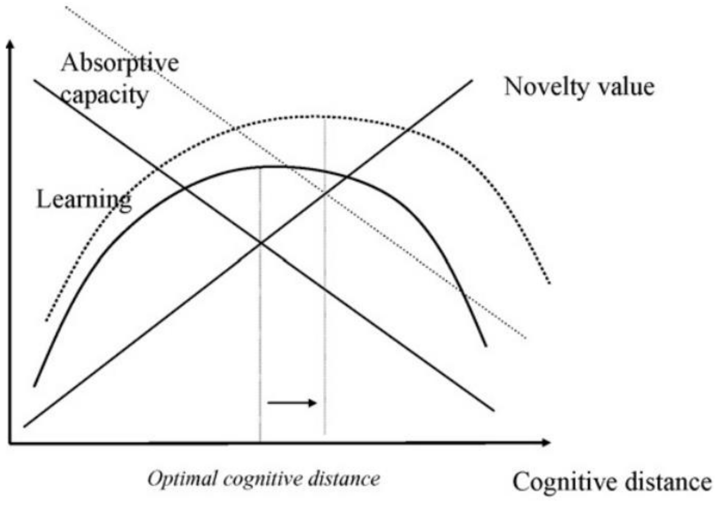

Figure 5: Optimal cognitive distance (Nooteboom et al., 2007).

In the context of EI, Gluch *et al.* (2009) argue that a firm's prior knowledge does not need to be technological, but can also be market-related, such as experience gained from benchmarking, or marketing research. This research follows their line, because radical EI is defined as involving both technological and market uncertainty (McDermott & O'Connor, 2002). Technological knowledge for EI ('enviro-technical knowledge') is technological knowledge that reduces environmental pressures of existing operations, most often a reduction in GHG emissions. Market knowledge for EI (or 'enviro-market knowledge') is knowledge about the demand for products and production processes with a reduced environmental pressure.

The average manufacturing SME is likely to have little basic environmental knowledge, or phrased differently: environmental knowledge remains outside of the firm's core competences. However, it does have prior knowledge about its manufacturing process, and is thus likely to possess basic knowledge about energy or material efficiency (i.e. enviro-technical knowledge). Likewise, any firm that is in contact with its clients might possess articulated knowledge on customer preferences, so enviro-market knowledge can also exist within the firm. Knowledge for EI can reside, sometimes latent, within the core competences as well, because our definition of EI is based on outcome and not on intention. Nevertheless, as this research concerns SMEs, a lot of enviro-technical and enviro-market knowledge is still too distinct from the basic knowledge (or in other words: the cognitive distance is too large to facilitate learning), making knowledge acquisition critical.

As knowledge base is a cumulative of all employees' knowledge, size is closely related to this variable, and should thus be taken into consideration when conducting a comparative analysis. It seems logical that larger firms are better at exploratory learning, and thus developing radical innovations. Although on the other hand, the 'incumbent's curse' argues that incumbent firms are less likely to develop radical, disrupting innovations due to their vested interests and path-dependency (Chandy & Tellis, 2000).

Related to internal knowledge base, a few expectations on the influence of knowledge sources in the adoption of EIs are presented. To the extent possible, it is tried to differentiate between radical and incremental EIs as well. In general, it can be expected that the cognitive distance between partners is higher for radical EI, than for incremental EI, because the latter usually builds on existing practices (Nooteboom *et al.*, 2007).

Customers are better able to provide market knowledge than technological knowledge. Customers tend to exert less influence on radical product innovations, because they are supposedly not aware what the technical requirements of that new product should be. In contrast, their knowledge is more applicable for incremental product innovations, as these are often based on user experience and comprise constructive feedbacks to the manufacturer (Colarelli O'Connor, 1998). However, based on the advantages of customer cooperation, it is hypothesized that knowledge interactions with customers can also provide benefits for radical EIs, for example to approximate the potential success of a new product or market (Lettl, 2007).

Suppliers, by their active partnership in the supply-chain with the manufacturing SME, are likely to possess technological knowledge on the production process. It is difficult to forecast effects on the radicalness of EI, but supplier knowledge is expected to be especially helpful in the adoption of incremental EIs, as these are related to the production process, rather than to the end-product. However, it is also argued that for a radical product innovation to become successful, supplier involvement is even essential, especially for product development and commercial performance (Song & Di Benedetto, 2008).

Exchanging knowledge with competitors will only happen when the focal firm's competitiveness will not be affected, so when firms are not, or only partly, in competition. As of yet, environmental performance is not generally conceived of as a competitive factor which makes knowledge exchange for EI likely to occur (Tether, 2002). Competitor knowledge is most similar, and can be both technological as well as market-related. Therefore, competitors will be a highly effective knowledge source for incremental EIs, but are not likely to play a role in the adoption of radical EIs, as these require genuinely different knowledge (Ritala & Hurmelinna-Laukkanen, 2013).

The government is very unlikely to directly provide market or technological knowledge. However, the role of the government is expected to be essential for the enhancement of incremental EIs, due to the double externality problem ('environmental externalities are impossible to appropriate') of EIs (Cecere, Corrocher, Gossart, & Ozman, 2014). Shortly stated, the 'Porter hypothesis' argues that stricter environmental regulations lead to improved environmental performance (Porter & van der Linde, 1995). On the other hand, it is argued that the government has the capability to stimulate the adoption of radical EIs as well, but it is unlikely that this will occur, taking into account the actors (including powerful interest groups) that might be opposed of potential changes that disrupt their favorable status quo.

External organizations (universities, research organizations and consultants) can provide valuable technological as well as market knowledge. Consultancies are able to tailor knowledge to the client (Tether, 2002), coming closer to the cognitive optimum distance. Universities are likely to produce fundamental knowledge, although technology transfer organizations improve translation toward industry actors. Regarding EI radicalness, no specific results can be hypothesized.

External knowledge complexity

In their literature review, Lane *et al.* (2006) identify three knowledge characteristics that influence a firm's AC, being knowledge content, knowledge tacitness, and knowledge complexity. Knowledge content - or 'know-what' - is an important determinant of absorption. Knowledge will only be internalized when student and teacher organization share common skills, or a knowledge base. And the more similar they are, the more smoothly knowledge is acquired (Lane *et al.*, 2006). In this research, the knowledge content factor has already been covered under the previous heading of cognitive distance. It is therefore discarded from the conceptualization of knowledge complexity.

Knowledge complexity is rather vaguely defined by Lane *et al.* (*ibid.*, 2006, p.846) as "the number of interdependent technologies, routines, individuals, and resources linked to a particular knowledge or asset". By contrast, Hansen (1999) offers as similar, but more workable conceptualization. He defines knowledge complexity as a composite of *knowledge tacitness* and *knowledge dependency*.

First, knowledge tacitness - or 'know-how' - relates to the extent to which knowledge is codified at the time of transfer, i.e. the degree to which it is formalized in written language (*ibid.*, 1999). Tacit knowledge is personal and context-dependent, which makes understanding more difficult and thus requires more face-to-face contact (Chen, 2004) or through past shared experiences (Hansen, 1999). In contrast, explicit, codified knowledge can be absorbed systematically, even over large distances.

Second, knowledge dependency is "the extent to which the knowledge to be transferred is independent or is an element of a set of interdependent components" (*ibid.*, 1999, p.87). Dependent knowledge is more difficult to acquire, as it requires more areas of knowledge to be interlinked. In the context of manufacturing processes, Zander and Kogut (1995, p.79) use the term 'system dependence', to refer to the degree to which new knowledge or capability is "dependent on many different groups of experienced people for its production". For example, a stand-alone component can be uprooted from the production process more easily, whereas a new product system is more difficult to integrate, as the preceding manufacture process needs to be redesigned (Hansen, 1999). Or, if the external knowledge is essential to all employees of the firm, this knowledge is highly interdependent and thus more 'sticky' (Zander & Kogut, 1995).

In sum, complex knowledge is knowledge that is either not (or hardly) codified, dependent on a lot of experienced people, or a combination of both. The more complex the knowledge is, the more difficult knowledge transfer and subsequent inter-organizational learning will be. It is hard to hypothesize on the relative influence of the different knowledge sources, because it depends on characteristics of the innovation project.

Relationship characteristics

Apart from knowledge-related AC drivers, other important drivers of exploratory learning are "non-knowledge aspects of learning relationships", which concerns how the innovation partners interact (Lane *et al.*, 2006, p.857). Learning relationships drive the 'ease of understanding' the external knowledge and does not play a role in how that knowledge should best be transformed or applied. Instead of learning relationship, Tödtling *et al.* (2009) speak of interaction mode, which they categorize on the basis of two dimensions: the *amount of external sources* and the *formality of the relation*. Apart from this, *frequency* of interaction is also important.

The amount of sources can be characterized as dyadic, or network (*ibid.*, 2009). However, as this research already applies a dyad-level perspective of AC, 'amount of sources' becomes redundant and is thus excluded.

The formality of interaction can be dichotomized into formal and informal relations. Formal relations entail traded market knowledge interactions and informal relations concern knowledge externalities and spillovers (*ibid.*, 2009). Also related to formality of interaction, Chen (2004) argues that the governance form of an interaction influences the transferability of the knowledge. He distinguishes between equity-based and contract-based interactions. Equity-based interactions are based on shared equity, such as joint ventures and equity investments, whereas contract-based interactions are formal agreements without shared equity. Chen found that tacit knowledge is better transferred in equity-based alliances, while explicit knowledge transfers smoothly in contract-based alliances.

Apart from formality, *frequency of interaction* is an important aspect (Wejnert, 2002; Zahra & George, 2002). More frequent interactions make the acquisition process more effective. Regarding frequency, Hansen (1999) found that strong ties – defined as frequent and close relationships - involve fewer transfer problems than weak ties (i.e. less frequent interaction), but weak ties can offer more novel insights than close relationships. Therefore, it is expected that radical EIs are established by interactions with distant partners, while incremental EIs are a result of close and frequent interactions. Looking at the conceptual model, interaction mode characteristics (formality and frequency) thus influence knowledge acquisition directly, but in the case of non-codified knowledge, also indirectly as they reduce knowledge tacitness.

Related to frequency and formality is trust. Trust is defined as “the belief that the other party in the relation will not act in self-interest on one’s own expense” (Werr, Blomberg, & Löwstedt, 2009, p.450) and is an important factor especially in establishing a new relationship. Trust is built up from past experiences, be it through direct interactions or indirectly through recommendations.

Notable excluded factors for exploratory learning

If external knowledge is to be recognized as valuable, this does not mean it will automatically be acquired. Two factors are important to denote, as they are both individually a necessary condition for knowledge acquisition to take place, being *activation triggers* and the firm´s *strategy*. These are excluded in order to keep the conceptual model simple. Moreover, the applied methodology will be backward looking. In other words, this research does not aim to predict but rather tries to explain *ex post*. The external context other than knowledge interactions is not of specific interest, and neither is the internal strategy of the firm. Nevertheless, a brief elaboration of both concepts is provided.

First, Zahra and George (2002) stress the importance of activation triggers. Activation triggers are defined as internal or external events which cause a firm to react. These events can be “organizational crises, performance failures or other events” such as radical technological shifts or governmental regulations (Gluch *et al.*, 2009, p.453). A recent example of an activation trigger in the context of the US could be hurricane Sandy, which raged the Eastern coast in 2012. Due to the link of hurricanes with climate change (Emanuel, 2008), it is possible that businesses perceive this of a trigger for EI. Lane *et al.* (2006) include in their model a role for ‘environmental conditions’ that are able to provide firms with incentives to increase their AC. Although most studies exclude this factor, they argue that future research should include it and look especially at how the firm’s competitive environments, as well as its regulatory environment are playing a role. Here, it is argued to exclude environmental conditions in the model, because regulatory actors and competitors are already included as important knowledge sources for innovation.

Second, the student firm’s strategy helps to explain exploratory learning, as strategy entails the way in which a firm competes in the market. It determines where to look for new knowledge. However, strategy actually affects all three learning processes of relative AC. To an extent, it determines “which areas of knowledge are valuable, which areas should be assimilated, and which areas should be applied” (Lane *et al.*, 2006, p.857). However, in relative AC, strategy is most influential for exploitative learning, and will thus be elaborated upon later.

Learning concept	Variables	Sub-concepts
Exploratory learning	Cognitive proximity	Student firm's knowledge base
		Teacher firm's knowledge base
	Relationship characteristics	Formality of interaction
		Frequency of interaction
	External knowledge complexity	Tacitness of knowledge
		Dependency of knowledge

Table 3: List of determinants of exploratory learning. Example: A student firm's knowledge base co-determines cognitive proximity, which in turn is affects exploratory learning.

2.3.3 Transformative learning

By acquisition, external knowledge is internalized. But in order for the new knowledge to be exploited, it first has to be assimilated or transformed. Assimilation of knowledge refers to the ability to interpret the acquired knowledge and subsequently to develop and refine it so that it can be combined with existing internal knowledge (Zahra & George, 2002). In the more classic relative AC, assimilation of knowledge depends on the internal existing capabilities of knowledge processing and is enhanced when knowledge processing of the teacher organization is similar to the student firm's (Lane & Lubatkin, 1998). Because "processing of knowledge is itself unobservable" (*ibid.*, 1998, p.465), it can be operationalized on the basis of a proxy: *organizational structure*. As this research constructed its own rejuvenated version of relative AC - viewing innovation from a dyad-level perspective, while emphasizing the student firm's dynamic capability to absorb knowledge – it is legitimized to analyze the organizational structure of the student firm only.

Van den Bosch, Volberda, and De Boer (1999, p.554) assessed the influence of organizational structure on absorptive capacity. They define organizational structure as "a type of infrastructure which enables the process of evaluating, assimilating, integrating, and utilizing knowledge in a specific way". They operationalize it based on methods of grouping activities, number of hierarchical levels and the division into different functional areas. In doing so, they distinguish between a functional organizational form, a division form and a matrix form. Functional structures have grouped "similar activities under major functional managers", with many hierarchical levels of small control spans (*ibid.*, 1999, p.554). Grouping in divisional structures is based on product-market combinations. These structures have fewer hierarchical levels and managerial staff possesses more authority. The matrix structure is "based on a dual grouping of activities, a dual hierarchy of authority consisting of few hierarchical levels, and a high degree of functionalization of management tasks." (*ibid.*, 1999, p.554).

Apart from organizational structure, Jansen, van den Bosch, and Volberda (2005) find a significant effect for cross-functional interfaces and job rotations on transformative capacity, as they help disseminating and transforming knowledge across different units or departments of the student firm.The more knowledge disseminates through the organization, the higher a firm's transformative capacity. Examples of cross-functional interfaces are task forces such as Green Teams, or liaison personnel. They enhance "lateral forms of communication that deepen the knowledge flows across functional boundaries and lines of authority" (*ibid.*, 2005, p.1001). Job rotation, or 'cross-training', is the degree to which employees switch roles or positions within the firm and the more diverse knowledge employees possess, the more efficient knowledge is transformed (*ibid.*, 2005).

Learning concept	Variable	Sub-concepts
Transformative learning	Student firm's organizational structure	Grouping of activities
		Hierarchy
		Cross-functional interfaces/ job rotations

Table 4: List of determinants of transformative learning. Example: A very hierarchical structure affects the student's organizational structure which in turn influences the firm's capacity for transformative learning.

2.3.4 Exploitative learning

Exploitative learning is the process of applying new knowledge in order to achieve commercial objectives (Cohen & Levinthal, 1990; Lane & Lubatkin, 1998). In this research, the objective is adoption of EI, either radical or incremental. It is definitely true that not all assimilated knowledge leads to innovation adoption. Lane and Lubatkin (1998) argue that, in the context of product innovation, adoption is more likely to take place if the student and teacher show similar dominant logics. Prahalad and Bettis (1986, p.490) defined dominant logics as "the way in which managers conceptualize the business and make critical resource allocation decisions - be it in technologies, product development, distribution, advertising, or in human resource management". Dominant logics determine how knowledge is applied. Because of its close resemblance with the overall strategy of the firm, I apply the term *strategic fit*. Strategic fit is the degree of overlap between the student and the teacher organization's strategies. Lane and Lubatkin (1998) operationalized it in the context of an alliance of two firms as the familiarity of the student "with the types of problems and projects that the teacher prefers". An additional important aspect for EIs is the level of environmental interest. Any firm can actively translate environmental values into its strategy and therefore this will be taken into account too.

Learning concept	Variable	Sub-concepts
Exploitative learning	Strategic fit	Student firm's dominant logics
		Teacher firm's dominant logics

Table 5: List of determinants of exploitative learning.

2.4 Conclusion

The theoretical framework of this paper consists of a rejuvenated version of relative absorptive capacity, viewing innovation from a knowledge management perspective. Knowledge is shared between two innovation partners, being a student and a teacher firm. Although a dyad-level perspective is applied, this research aims to focus on the student firm, and especially its organizational mechanisms and their influence on AC, and ultimately on EI radicalness. Radicalness of EI is based on internal technological uncertainty and disruption, as well as external market uncertainty and disruption. It is important to take in consideration the innovation type, as they are expected to be constituted on totally different innovation partners. Other variables include firm size, which is a predictor of the student firm's knowledge base, and activation triggers, which are implicitly covered by knowledge interactions with competitors and regulatory bodies. Please see Table 6 for a complete list of variables and their antecedents.

Complete list of variables*			
'Rejuvenated' relative AC	Exploratory learning	Cognitive proximity	Student firm's knowledge base
			Teacher firm's knowledge base
		Relationship characteristics	Formality of interaction
			Frequency of interaction
		External knowledge complexity	Tacitness of knowledge
			Dependency of knowledge
	Transformative learning	Student firm's organizational structure	Grouping of activities
			Hierarchy
			Cross-functional interfaces/job rotations
	Exploitative learning	Strategic fit	Student firm's dominant logics
			Teacher firm's dominant logics
Environmental innovation	Innovation radicalness	Technology	Technological disruption
			Technological uncertainty
		Market	Market disruption
			Market uncertainty
	Innovation type	Product	
		Process	
Other variables	Firm size		
	Activation triggers	Industry conditions	
		Regulatory conditions	

Table 6: Complete list of variables
**Core concepts on the left, with each antecedent to their right. Example: Student firm's knowledge base is an antecedent of cognitive proximity, which in turn is an antecedent of exploratory learning, which is in turn an antecedent of relative absorptive capacity.*

Chapter 3. Methodology

This chapter presents the research design and gives insights into the methodological choices that have been made in the research process. The research strategy comprises a comparative cross-case study, with qualitative data derived from interviews. In paragraph 3.1, a brief elaboration of how and why to apply a cross-case study is presented. Paragraph 3.2 describes the data collection phase, which consists of case selection, a data collection preparation phase, the interviews, and additional case exclusions. Paragraph 3.3 contains elaborations on the data analysis. In the data analysis, operational steps are presented which should enhance this study's replicability. The steps include ex post classification of cases (Par. 3.3.1), quantification of data (Par. 3.3.2) and their application for radar charts, and finally, the comparative case study. Paragraph 3.4 contains some notions around the quality of the methodology.

3.1 Research strategy

The research aim, as well as a few other methodological decisions determine which research strategy is best fitted. In those decision one always has to take feasibility into account as well. The research aims are not theory-oriented, such as generating or testing hypotheses, but are rather empirically-oriented, as this study applies a conceptual model to identify co-variation among concepts, with the aim to make practical policy recommendations. Making recommendations to a larger population of firms, as well as to the public sector, implies a purpose of generalization. The research is exploratory, as it analyzes the knowledge-related variables that are at play in the adoption processes of incremental and radical EIs.

Firstly, the study's characteristic of generalizability asks for a research strategy that has both internal and external validity. It needs to take into account case-specific factors and pay attention to contextual factors, but also the cases need to be representative of a wider population, otherwise the recommendations will not be valid externally.

Secondly, this study's exploratory nature asks for a middle-ground between induction and deduction. Induction is looking at reality through a predetermined lens or theory, whereas deduction is reverse, and based on observation from which theory is (re)constructed. On the inductive side, the conceptual model is used to identify variables and anticipate on the results. On the deductive side - apart from applying a low threshold for inclusion of variables into the conceptual model (the model has many variables for a reason) - the researcher takes an open stance toward new variables that were not found in the literature.

The chosen research strategy is a cross-case study (Gerring, 2004). Gerring (p.342) defines a (single) case study as "an intensive study of a single unit for the purpose of understanding a larger class of (similar) units", hereby stressing the aim of generalization. Case studies are especially suited in situations where the concept under study is difficult to separate from its context (Soosay, Hyland, & Ferrer, 2008). This is definitely the case when looking at the degree of interaction in innovation adoption processes. Moreover, the conceptual model presented in Chapter 2 is relatively complex, which calls for an 'intensive study'. However, as this research has time constraints, the intensity of study is limited to a single interview per unit of analysis (i.e. manufacturing firm).

Case studies exist in different forms, classified along spatial and temporal dimensions (Gerring, 2004). Taking the speed of innovation processes into account, temporal variation – or diachronic research - is deemed impossible in the five months' timeframe of this research. However, as it aims to compare sets of cases, a spatial variation is applied. The specific case study applied is the *cross-sectional case study*, or cross-case study.

An important methodological decision regards the scope of proposition, which refers to whether to focus on depth or breadth (Verschuren & Doorewaard, 2010). This research finds itself in a middle-ground, as it acknowledges particularities of individual cases, but the research strategy should also contain external validity, or generalizability, as it also aims to make recommendations for a larger population based on valid comparisons between cases. A delimiting factor in choosing the strategy is time. Taking feasibility into account, a cross-case study would strike the best balance between an in-depth analysis that respects the particularities of cases, as well as provide enough external validity to make generalizable recommendations.

Another trade-off between single- and cross-case study research is unit homogeneity (Gerring, 2004). Single case studies are less representative of their population. The study aims to compare radical and incremental EIs. This can be done by taking one case per EI, but as there are many factors influencing the adoption process, one would rather have more cases per EI which enhances the overall representativeness of the sample cases. The larger the sample, the lower the comparability, while smaller samples lead to a reduced representativeness. While setting up the research design I aimed - within the dedicated timeframe - to gather information of about 12 to 18 cases, which would lead to information of four to six incremental, intermediate, and radical EIs each.

3.2 Data collection

This paragraph describes the data collection phase, and starts off with the considerations that played a role in the selection of cases. This process is extremely important in doing qualitative studies. Then some more practical comments are made about how the interviewees were targeted in the data collection preparation. Subsequently, an overview of the interviews is provided, as well as some relevant notions on case exclusion, because some of the cases did not fit the specified sample.

3.2.1 Case selection

Seawright and Gerring (2008) distinguish different case selection techniques. Case selection is important "for in choosing cases, one also sets out an agenda for studying those cases" (*ibid.*, 2008, p.294). The applied case selection technique is a most similar method. In this method, the research requires a minimum of two cases that show *most similar* scores on all variables, except for the dependent variable (radicalness) and the independent variable of interest (knowledge interactions).

As explained above, this research will compare cases based on outcome on the dependent variable. Ideally, one would want to compare cases that are most similar on the independent variables and different on the dependent variable, a process called *matching*. However, in observational studies, it is almost impossible to find cases that score very similar on the desired variables (Seawright & Gerring, 2008). Alternative ways to match cases exist, such as *exact* matching, but these are quite time consuming as they rely on large *n* data. For example, by means of a survey, data could have been gathered about covariates (i.e. control-variables) such as knowledge base, organizational mechanisms, firm size and industry.

In setting up the research design, it has been decided to exclude exact matching, because it was deemed infeasible within the allocated time. Instead, to increase cross-case comparability, I opted to conduct an *ex post* classification of cases into three groups, dependent on the outcome of the dependent variable (incremental, intermediate, and radical). How this is done is explained in Paragraph 3.3. Because data collection proved to be time consuming, all contacts that responded positively to an interview request - and *seemingly* fitted the sample - were actually interviewed. In case afterwards they did appear unfitting, they were excluded (Par. 3.2.3).

3.2.2 Data collection preparation

Initially, the idea was to collaborate with my internship supervisor Arend de Jong and use past and prospective clients of RenewThink for case studies. Unfortunately, there was a mismatch which affected the data collection feasibility: RenewThink is specialized in providing management advice to larger firms, and specifically not to manufacturing firms. Neither did the company possess explicit information about (technological) EI processes. Nevertheless, RenewThink's knowledge of and experience in Western Massachusetts (Boston and the North Shore area in specific) were useful, especially in the beginning. For example, RenewThink is a member of the Greater Boston and the North Shore Chamber of Commerce (CoC) which provided access to their member directories. Through RenewThink, I have also attended ten networking events, including breakfast seminars, networking luncheons, and conferences. These activities facilitated for an understanding of the context in the sense of federal- and state-level regulations and stakeholders' perceptions of sustainability. These were not part of my formal data collection strategy, although they did result in two interviews (Colonial Printing and J&J). The formal data collection strategy was as follows.

First, it was aimed to get personal leads through umbrella organizations. Umbrella organizations were any organizations that could bring me closer to the sample and included chambers of commerce (CoCs), governmental liaison offices, industry associations (e.g. biotechnology and medical device industries), business networks constructed around sustainability, advocacy groups, and others (see Table 7).

Umbrella organization	Website	Results
Boston CoC	www.bostonchamber.com/	Information on website
Salem CoC	www.salem-chamber.org/	Information on website
MetroWest CoC	www.metrowest.org/	Information on website
Worcester Regional CoC	www.worcesterchamber.org/	Information on website
Western Mass Economic Developm't Council	www.westernmassedc.com/	Information on website
Mass Biotechnology Council	www.massbio.org/	Information on website
Mass MEDIC	www.massmedic.com/	Information on website
Mass Technology Leadership Council	www.masstlc.org/	Mismatching members
Environmental League of Massachusetts	www.environmentalleague.org/	Mismatching members
Sustainable Manufacturers Network	www.linkedin.com/	Mismatching members

Climate Action Business Association	www.cabaus.org/	Mismatching members
Sustainable Business Network Mass.	www.sbnmass.org/	Mismatching members
North Shore Technology Council	www.nstc.org/	Mismatching members
Tech Networks Boston	www.techboston.com/	No timely contact
Associated Industries Massachusetts	www.aimnet.org/	No timely contact
Mass. Manuf. Extension Partnership	www.massmac.org/about.htm/	No timely contact
Massachusetts Clean Energy Center	www.masscec.com/	No timely contact

Table 7: List of umbrella organizations

On the assumption that 'warm' personal contacts would generate better leads than 'cold' contacts, I tried to make personal contact with representatives of any of the umbrella organizations and see if they would enable access to manufacturers. After ten days of sending out e-mails and phone calls, and trying to get personal introductions, not a single lead was obtained. This was either due to mismatching member organizations (e.g. some organizations were only focused on large firms, some on start-ups, some protected their databases and did not see an interest in disclosing information) or bureaucratic restrictions (i.e. difficult to speak to the right person). Others have open data on their websites which did prove useful. Nevertheless, after ten days the data collection strategy was changed from personal quality introductions to a more quantitative approach.

Second, by making use of the umbrella organizations' membership directories, numerous websites of manufacturers were screened. Screening was done quickly, and informally, but with two important aspects: potential sample fit and likelihood of finding an EI. Possible interviewees were employees of any manufacturing firm that was likely to have recently adopted a technological innovation with environmental benefits. These included manufacturers that advertised themselves on websites as being 'green', or having more efficient products, but did also include ones who didn't, because process EIs generally do not require such marketing campaigns. If manufacturers met the criterion of size - although this is not always explicitly stated on the website - they were added to the list. At last, the list contained a total of 135 manufacturers that seemed (from their respective websites) as fitting the applied definition of SME (no more than 300 fulltime jobs).

Contacting was done in a structured way. First, an e-mail would be sent out, which contained a short message in which I declared interest in the company, some personal information, as well as some information about the research question and perspective. The message was intentionally kept short, not to distract the receiver too much from daily work. The message was also flattering, which is in accordance with American norms of politeness. The messages were standardized in lay-out, but the content was custom-made and tailored to the receiver. Tailoring was based on any information obtained from their websites, and most often concerned references to their sustainability practices, innovation policies and/or manufacturing capabilities. Second, in case of non-response a phone call would be conducted three workdays later. In case answered, I tried to get in touch with the right person (preferably the manager, or VP Operations). In case no answer, a phone call would be scheduled a day later, and so forth. In total, of the 135 manufacturers, 83 manufacturing firms were contacted (i.e. sent out e-mails or made phone calls). Although the statistics are not recorded, many firms did not respond in first instance and had to be called back multiple times. In general, three main barriers to interviews were identified, playing a role especially for manufacturing SMEs.

- *Time constraints:* Manufacturing firms, and especially managers and employees in production/engineering are busy and work on short timelines and hard deadlines.
- *Intellectual property:* Some firms expressed a fear of disclosing internal proprietary knowledge with a (foreign) student. This could sometimes be attenuated by emphasizing the research perspective of knowledge management and the researcher's background in social science, rather than engineering.
- *Interest:* A number of firms did not see their interest in participating. This could sometimes be attenuated by sketching the relevance of the research, as well as the business services of RenewThink. Persuasion and sales skills seem to be very important.

In the end, eleven manufacturing firms agreed to be interviewed, which resulted in data of thirteen cases.

3.2.3 Interviews

Because the focus is on the absorptive capacity of the firm, only employees of the manufacturing SMEs are interviewed. Per case, only one employee is interviewed, except for ASC of which both the director as well as the director of quality were interviewed. Eleven interviews have been conducted, each lasting between 30 and 60 minutes. All but one of the interviews were conducted in person, except for Colonial Printing, which was conducted over the phone. The phone interview proved to be more challenging, as there was a feeling of preventing the conversation from dropping dead, although this could have also been due to the fact that this was only the researcher's second interview and the researcher still needed to acquaint himself with structuring the answers. The same was true of the very first interview (with ILT), but the interview got interrupted for five minutes, in which the answers were structured, which ensured none of the questions were left unanswered. The interviews were semi-structured around three basic topics: characteristics of the organization, characteristics of the EI, and the KIs per source. For an interview guide, see Appendix B. A table was included to structure the answers about KIs: the boxes were 'ticked' when the interviewee had touched upon that specific subject. This increased the overall data completeness.

Regarding the interviewees, it was aimed to interview only employees that have been actively involved in the innovation process, preferably from the start to the end, keeping data loss to a minimum. Also, it was aimed to interview employees that have had influence in the (relevant) decision-making processes of the sourcing strategies, as the latter potentially gives insights into non-decisions as well. In five cases this was the director, in other cases this was someone responsible for technical or marketing operations. An overview of cases and interviewees is presented in Table 8.

Overview of cases and interviews							
Case	**Innovation case**	**Innovation type**	**Company**	**Interviewee**	**Position**	**Industry**	**Environmental benefits**
A	Canopy retrofit LED light	Product	Intern'l Light Technologies (ILT)	Pete Couture	Director	LED lighting	Energy efficiency
B	Hybrid UV press	Process	Colonial Printing (CP)	Joe LaValla	Director	Printing	Energy efficiency, material efficiency (paper, ink)
C	Klear Can	*Both*	Kortec	Russell Bennett	Director Sales & Marketing	Plastics molding	Less intensive production, less transportation
D*	Remote phosphor technology	*Both*	RemPhos	Dave Gershaw	Founding president	LED lighting	Energy efficiency
E	Mercury-free lighting	Product	LuxteL	Paul Beech	Managing member	Surgery lighting	Less hazardous waste
F	Brazing furnace	Process	LuxteL	Paul Beech	Managing member	Surgery lighting	Less transportation
G	Drying machine	Process	Draper Knitting (DK)	David Wedge	Technical fabrics product manager	Fabrics	Energy efficiency
H	Sewing machine	Process	American Surgical Company (ASC)	Erik Piasio & Michael Alouane	Managing Director & Director of Quality	Surgical neuro-patties	Energy efficiency, material efficiency
I	Degradable coffee Cartridges & valves	Product	Urthpact	Michael Pousland	VP Operations	(Bio)plastics molding	Less plastic waste
J	Manual low-flow faucets	Product	Symmons	Steven Kinney	VP Manufacturing	Plumbing products	Water efficiency
K	Lead-free valves	*Both*	Symmons	Steven Kinney	VP Manufacturing	Plumbing products	Less hazardous waste
L*	Less harmful packaging	Process	Johnson & Johnson (J&J)	Wes Walker	Director of Engineering	Medical devices	Less hazardous waste
M*	*N.a.*	*N.a.*	Fluorolite	Greg Pink	Founding director	Lighting lenses	*N.a.*

Table 8: Overview of cases and interviews ranked chronologically of the moment of interviewing. N.a. = not applicable.
**Cases D, L, and M are excluded from analysis, because they do not qualify for the defined sample (see Par. 3.2.4).*

3.2.4 Case exclusions

After conducting the interviews and scrutinizing the transcripts, a few cases were identified that did not match the sample. The cases are Fluorolite, J&J, and RemPhos, while there also has to be made a critical note on the case of Draper Knitting.

The case of Fluorolite was excluded for the simple reason that they did not adopt a single technological innovation in the last two decades. Granted, the interviewee had already admitted this, but it still seemed an interesting case, perhaps for setting the context as a non-innovator. Fluorolite does not and will not employ a growth strategy, because it relies on a very effective business model with large profit margins and is able to produce single items for customers, which allows their processes to be manually operated and at slow pace. Automation - a process which almost inherently provides environmental benefits due to efficiency gains - has not occurred in Fluorolite in twenty years.

The case of J&J was excluded for the same reason as Fluorolite, and this was also known before the interview was conducted. J&J is the world's largest medical device company with 126.500 employees. Regardless, an interview with Wes Walker, former Director of Engineering, was still conducted because it increased the understanding of how drivers and barriers of EIs differ for SMEs and large corporations. For example, in this case a small incremental change in a product's packaging led to radical operational changes on a global scale.

During the interview with David Gershaw of RemPhos, two innovations were discussed: the spin-off of RemPhos from multinational Osram Sylvania, and the acquisition of a new plastic sheet extruder. The former disqualifies because it is both an organizational innovation and the innovating company is a multinational company. Unfortunately, the new sheet extruder was excluded because it did not have any environmental benefits that Gershaw knew of.

Finally, it is also noteworthy to critically look at the case of Draper Knitting, a fabrics manufacturer who acquired a brand new dryer. This piece of machinery is assumed by the researcher to have environmental benefits as it replaced two machines (one from the 1940s and one from the 1950s). Dave Wedge of Draper Knitting could not affirm or reject the fact that it actually had environmental benefits, but the dryer runs much faster and as it was acquired brand new, it would very likely do so in a modern, more efficient way.

3.3 Data analysis

In order to go from the collected data to clear answers to the research questions, a number of steps have to be taken, which altogether constitute the data analysis. In Figure 6, the general process of data analysis is presented.

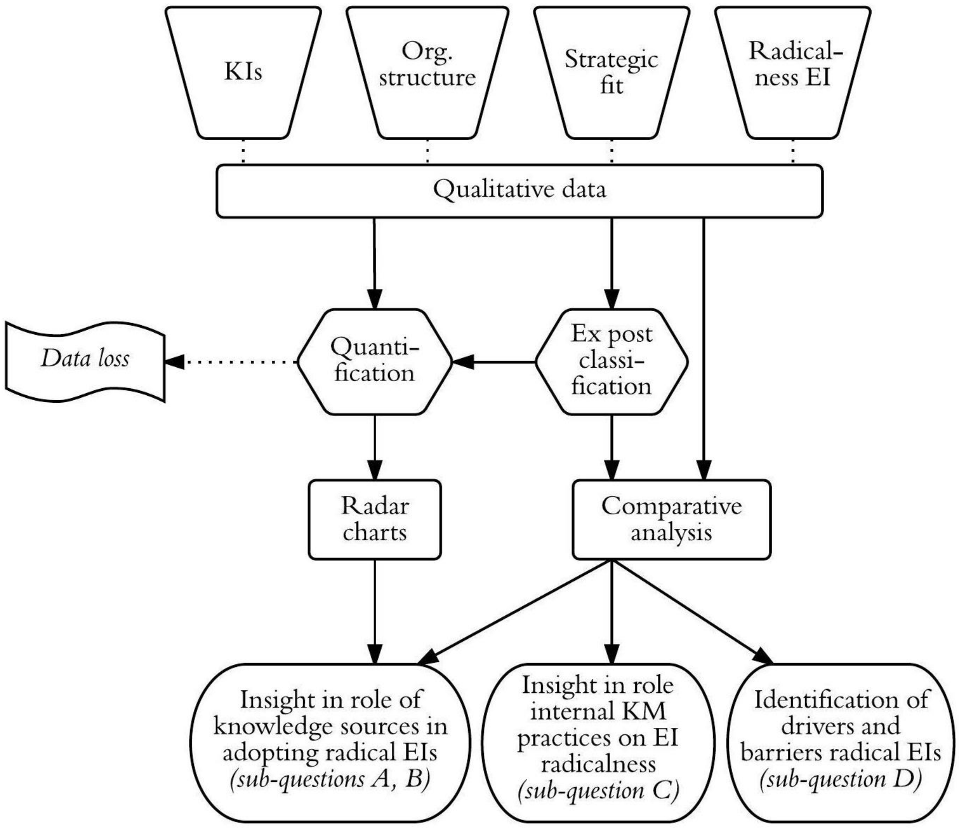

Figure 6: Data analysis. The different processes and tools that will lead to the results.

As discussed in paragraph 3.2, qualitative data were collected by means of interviews. The qualitative data consist of information about knowledge interactions (KIs), organizational structure, strategic fit and EI radicalness (depicted on top of the figure). The data are coded by means of NVivo 10 coding software. It is done so in a deductive manner, where the labels correspond to the variables of the model of rejuvenated relative absorptive capacity (see Appendix A).

Two processes are important before starting the actual analysis, being *ex post classification* and *quantification of data* (depicted in hexagons). In order to conduct a cross-case comparison, the relevant clusters of cases need to be identified. This is done through ex post classification (Par. 3.3.1). Ex post classification generates three different groups being *radical*, *incremental* and *intermediate* EIs. Another methodological process that is conducted is operationalization, or quantification of data (Par. 3.3.2). Quantification is needed to visualize the different KIs in radar charts. The qualitative data are complex and context-dependent, and will thus be presented in a narrative. Radar charts complement the narrative, as they provide the reader with results at one glance. A disadvantageous consequence of quantification is *data loss*. This needs to be taken into account while interpreting the results of the radar charts.

As discussed above, the main method of this research is the comparative case study analysis. This will be based purely on qualitative data from the interviews. The classification of radical and incremental and intermediate EIs is obviously important in this research stage. The results are presented per EI cluster. So first, descriptions of supplier KIs preceding incremental EIs are presented, followed by a brief analysis of similarities and differences. Then the same for intermediate and radical EIs, and followed by a conclusion. The next paragraph then considers customer interactions and so forth. Altogether, the cross-case analysis and the radar charts enable for answering sub-questions A and B.

Sub-question C, about internal knowledge management processes and transformative learning capacity, is also answered by means of a cross-case comparison. The manufacturers' different organizational structures will be presented in a table. Knowledge dissemination is not relevant for all EIs, as this depends on the dependency and tacitness of the internalized knowledge (i.e. knowledge complexity, see Par. 2.3.2). For all EIs with a relatively high level of knowledge complexity, an analysis is provided (see Par. 4.4).

Sub-question D is answered by identifying observed and potential barriers of EIs (Par. 4.5.1), as well as analyzing the EI drivers per cluster and presenting them in a table while distinguishing between direct and indirect drivers (Par. 4.5.2). Moreover, the governmental interactions and influence are analyzed per EI cluster (Par. 4.5.3).

In order to enhance replicability of this research, elaborate descriptions of the processes of ex post classification and data quantification are presented in the following two paragraphs.

3.3.1 Ex post classification

In order to make comparative claims about incremental and radical EIs, it is first required to identify cases as incremental or radical. Ex post classification is thus a necessary preparatory step in the process. It is discussed in this paragraph, because it is an analysis in itself, namely of EI radicalness. As elaborated in the theoretical section (Par. 2.1) innovation radicalness is based on four aspects: internal technological disruption, internal technological uncertainty, market disruption, and market uncertainty.

Firstly, qualitative data are coded by means of NVivo. Any comments about to what extent internal operations have been changed and how much effect it had on the market are coded under any of the four aspects of EI radicalness. Qualitative results are presented in a table, summarized in bullet points. An example for cases A and B is presented in Table 9.

EI case (company)		Internal radicalness		External radicalness	
		Technological impact	*Technological uncertainty*	*Market impact*	*Market uncertainty*
A	Canopy LED Light (ILT)	- Component change. - ILT does only final assembly. - Very few employees affected by the new product.	- No learning/ training required, only some instructions to assembly workers.	- Industry already makes these lights, but ILT focuses on retrofits which is a new approach.	- Indirect customer relations. - Governmental rebates provide incentives
B	Hybrid UV Press (CP)	- New machine, replaced two existing machines.	- Supplier training, 6 weeks, to understand technical operations.	- Technology is novel (3-4yr old) - Close monitoring of competitors to see the "bumps to come out".	*N.a.*

Table 9: Example of EI radicalness analysis. N.a.=not applicable

Subsequently, the cases will be arranged from incremental to radical on an aggregate scale of radicalness. Please note that market uncertainty, presented in the far right column, does not play a role for EIs that are only created for self-interest, which - by logical reasoning - is assumed to be the case for any process innovation. In calculating the aggregate EI radicalness, therefore, market uncertainty is excluded from analysis. It would result in eschewed aggregates. See Figure 7 for an example of how to analyze EI radicalness with three fictitious cases A, B, and C.

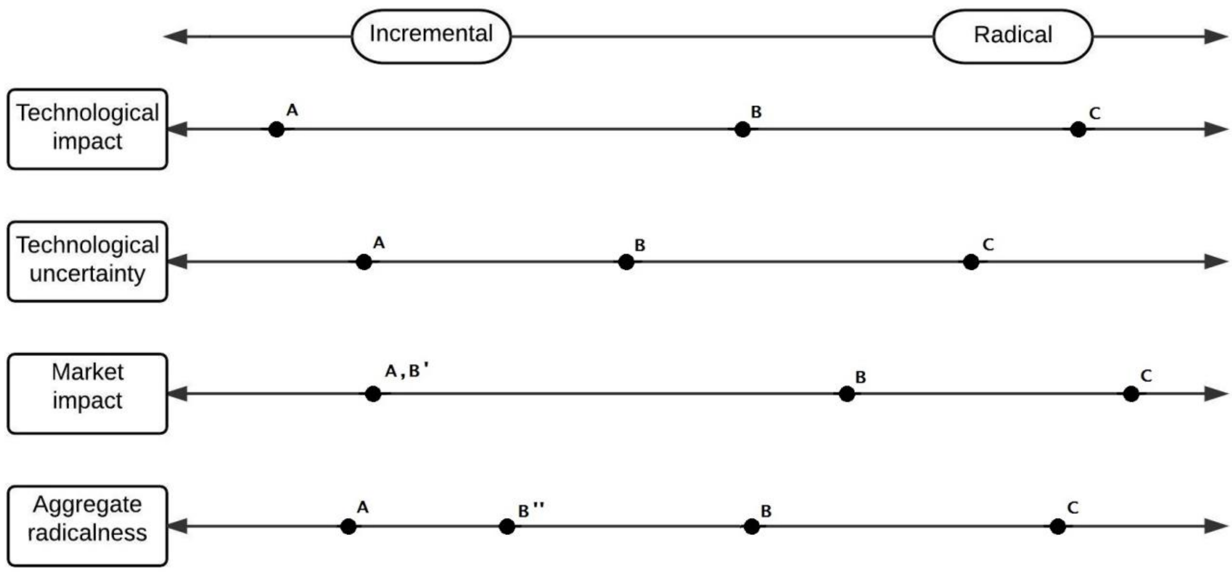

Figure 7: Analysis of radicalness of three fictitious cases A, B, and C

Four continuum scales are depicted. One each for the three relevant radicalness aspects and the one representing *aggregate radicalness*. The most incremental innovations are depicted on the left, the radical ones on the right. In deciding how to score the cases, no explicit quantitative ranking strategy was applied. Rather, it was based on the researcher's substantive knowledge about the cases. It was aimed to keep the radicalness spread as wide as possible. Each of the three radicalness aspects is weighed equally. This is considered to be less ambiguous, because this research includes both product and process innovations. For example, if only product innovations would have been considered, then an emphasis could have been put on market impact, because this is the main aim of developing a new product.

It has to be admitted that this way of classifying cases is arbitrary and perhaps difficult to replicate. However, to increase validity and reproducibility, two mechanisms should relieve these flaws to a certain extent.

First, it is aimed to select three clusters: one incremental EI cluster, one radical EI cluster, and additionally, a cluster of intermediate *EIs*. Those clusters are identified by drawing a virtual line at one-third and two-thirds of the continuum scale. The most clear-cut results follow from an analysis in which some of the ten cases are extremely incremental and some are extremely radical, although it is not expected to be the case. Creating a buffer group of intermediate EIs could enlarge the cleavage between incremental and radical, and help to show clearer differences. Additionally, the intermediate group could also help identifying co-varying relationships between knowledge interactions and EI radicalness, instead of a mere (less valid) interpolation between the two extremer groups.

Secondly, to increase validity, it is aimed to exclude possible *ambivalent* cases. Ambivalent cases would be cases that score ambiguously for the three radicalness aspects. For example, if case B (see Figure 7 above) scored very low for market impact (i.e. B'), it would belong to the incremental cluster of market impact. But B scores intermediately for both technological impact and uncertainty. Case B's aggregate score (i.e. B'') would then be ambivalent and thus excluded from further analysis.

3.3.2 Quantification of data

The qualitative data are quite complex, and will thus be presented in a classic narrating manner, which pays attention to the qualities of the data. Additionally, qualitative data are reduced to numbers, a process which is referred to as quantification. The first step of quantification is to reduce comprehensive answers of interviewees into summarized pinpoint words that resemble the fundamental relationship with the different knowledge sources. These are presented in a table, of which an example is given below (Table 10).

	Int'l Light Technologies	Colonial Printing	Kortec
Supplier	Formal ad-hoc, incl. some design services	Training	Joint development
Customer	Direct demand	-	Direct demand
Competitor	Monitoring	Friendly consultations	Trade shows
Advisory	Project-based	-	-
Regulatory	Rebates/technical standards	-	Restrictions food safety

Table 10: Example of summarizing qualitative data as part of the quantification process.

Based on empirical results, the qualitative data are codified into numerical values ranging from 0 to 4. Overall, '0' represents an absent KI, whereas '4' represents a KI that is relatively most formal and occurs most frequent compared to others. Scaling is done on a relative basis, trying to keep the distances between every single point as equal as possible. Please see Table 11 below for a full representation of codifications, arranged per knowledge source.

Codifying qualitative external knowledge interactions							
Supplier interaction		**Customer interaction**		**Competitor interaction**		**Advisory interaction**	
Joint development	4	Joint development	4	Joint venture, merge	4	Formal, project-based interactions	4
Structural interactions	3	Final phase interaction (e.g. prototype testing, feedbacks)	3	Friendly consultations	3	-	-
Any form of training/ formal/ ad-hoc interact'ns	2	Direct formal demand	2	Direct formal interactions (e.g. trade shows)	2	Informal interactions	2
Transaction-based interaction	1	Indirect trend identification, no direct interaction	1	Indirect monitoring web/ buying competitor's product/ occasional cross-hiring	1	-	-
No interaction	0	No interaction	0	No interaction	0	No interaction	0

Table 11: Scores of the knowledge interactions with external sources.

Please note that regulatory interactions are excluded from this analysis due to the different role they play. Governments can provide incentives (grants, rebates) and regulations (restrictions, reporting). Hansen *et al.* (2002) explicitly distinguish between 'regulatory networks' and 'knowledge networks' (see Par. 2.2). This research adopts their view, because interaction with regulatory bodies is most often unilateral (from government to subject), relatively non-negotiable, with a consequence that frequency or intensity of interactions is not affecting the outcome. This is due to the legislative character of the government that sets itself apart from other, more equal organizations.

Interactions with advisory organizations (i.e. consultants, universities, and research organizations) did only occur in either formal, or informal ad-hoc interactions. In this case, codification was then done on a three-point scale, but also ranging from 0 to 4, so that the radar chart scale is the same.

By making use of Excel, the results of the analysis will render radar charts which indicate the intensity of KI per source.

3.4 Reflections on methodology

This section assesses the quality of the research methods around different issues and provides background into the methodological decisions that are made in the process. Good *quantitative* research should be valid, reliable, and replicable (Morse, Barrett, Mayan, Olson, & Spiers, 2002). In the context of interpretive, *qualitative* research, Shenton (2004) argues for a different terminology, although in essence it covers the same aspects. Instead of internal validity, qualitative research should be *credible*. Secondly, while good quantitative studies are externally generalizable, sound qualitative studies are *transferable*, and, thirdly, reliable qualitative studies should be *dependable*. The more credible, transferable and dependable a qualitative study is, the more trustworthy it is. Shenton presents a number of strategies through which trustworthiness can be enhanced. Burke Johnson (1997) also presents strategies to enhance internal and external validity. The most relevant strategies are enlisted in Table 12.

Strategy	Aim
Adoption of well-established methods	Internal validity
Development of familiarity with respondents' culture	
Data triangulation	
Analyst triangulation	
Negative case analysis	External validity
Random sampling	
Provision of background data/context	
In-depth description of methodological steps	Reliability
Use of mixed methods	
Recognition of study's limitations	Objectivity
Admission of researcher's beliefs	

Table 12: Strategies to enhance trustworthiness of qualitative studies. Adopted from Burke Johnson (1997) and Shenton (2004).

3.4.1 Internal validity

Internal validity refers to the "degree to which a researcher is justified in concluding that an observed relationship is causal" (Burke Johnson, 1997, p.287). A major drawback of this research is that innovation processes often take multiple years to be completed. A cross-time series design would have been more valid, however it is legitimized to abstain from that, because of the short time period in which this research is carried out.

The internal validity of this research can be strengthened by triangulation. Yin (2013) describes four types of triangulation: analyst triangulation, theory/perspective triangulation, data source triangulation, and methods triangulation. The first two are impossible due to characteristics of this research (i.e. this project is individual and exploratory rather than explanatory). A flaw of this study is definitely that it does not directly triangulate data sources. As the focus of this research is on dyadic knowledge relationships, it would be more valid to also interview knowledge sources. Assuming that each manufacturer interacts with three knowledge sources for an EI, I would have been only able to discuss between three to five cases, in the allocated time. Fact is, however, that I excluded this possible alternative research design for two reasons. First, this research aims to make at least some generalizable claims which would have been really weak in case, for example only two incremental and two radical cases were analyzed. Second, previous research has focused less on the internal organizational mechanisms as part of absorptive capacity. Accordingly, a substantial part of the interview questions regarded these mechanisms.

3.4.2 External validity

External validity - or generalizability - refers to the extent to which the results of the sample cases can be generalized to a larger population. This research design consists of a most similar case study, which is, according to Seawright and Gerring (2008, p.298) well-suited to make generalizable claims, but only if the sample cases are "broadly representative of the population". Whether this latter statement is true depends on the case selection techniques and the biases involved in the process. If case selection was randomized, then it can be assumed to be representative of the population, although sample size still needs to be included when interpreting the results.

Case selection was quite randomly done, on the basis of screening websites for words related to innovation and sustainability. In the screening process, prospective interviewees were informally labeled as 'high potential' in case they showed environmental interest and/or proactive innovation policies. As the research aims to uncover adoption processes of radical EIs this could have resulted in a selection bias toward radical EIs. However, within the geographical boundaries this informal labeling technique was not maintained, as it was very difficult to find respondents. Instead of only targeting manufacturers that would seem to have a higher likelihood of having adopted (radical) EIs, at some point, *any* small- to medium-sized manufacturer was targeted, simply because of the need for respondents.

Another, more general selection bias is a common flaw occurred in most innovation research and concerns the focus on successful EIs. For example, Hansen (1999) tried to reduce the selection bias by including successfully developed innovations, as well as innovation projects that were ultimately cancelled. This research has not done so, as it excludes all the cases in which KIs did not lead to innovation. On the one hand, the researcher could have included a so-called negative case, but on the other hand, its added value would be questionable. For example, the case of Fluorolite could be included but then again, as Fluorolite had not conducted any innovation. They did have supplier and competitor interactions, but not with the aim of adopting innovative technologies. Rather, I could have asked innovating firms about innovation projects that have not been completed.

It is noteworthy to say that there could have been a response bias as well, as manufacturers of successful performance are more willing to share their information. This could have been the case for RemPhos, Urthpact and Kortec, who are all marketing sensitive companies. The response bias is a little overstated, because in approaching the prospective interviewees, the focus was put on technological innovation, rather than on sustainability explicitly. This was possible, due to the wider definition of EI that this study applies.

Apart from case selection biases, generalizability is dependent on sample size (Yin, 2013). The sample size in this research is quite low, while the amount of variables is quite high. This negatively affects the generalizability of the results. To improve generalizability, either more cases could have been selected, or a simpler conceptual model could have been constructed.

3.4.3 Reliability

Reliability refers to the extent to which the research would have ended up with the same results in case it was conducted again, in the same context using the same methods and respondents (Shenton, 2004). Two important ways to increase a qualitative study's reliability, or transferability, are providing a detailed description of the methodological steps. This is done in Paragraph 3.2 and 3.3. A second strategy is to use more than one method to show the results similarities. This study unfortunately only uses one method. In the process, it was opted to conduct a qualitative comparative analysis (QCA), which is a middle-road method between qualitative and quantitative research. Regrettably, the combination of data insufficiency (i.e. too superficial) and an abundancy of variables did not facilitate for valuable results, and the QCA has thus been dropped in the process.

3.4.4 Objectivity

A flaw of qualitative studies is that they are more reliant on the perspective of the researcher. It is thus prey to subjectivity. To reduce subjectivity and increase overall trustworthiness, the researcher can present its beliefs and backgrounds, as well as recognize the limitations of this study. Recognition of the study's limitations are presented in this very paragraph, as well as in Chapter 6. A short note on the researcher's background would be sufficient and is presented on the following page.

Jens Gronheid is a Dutch, 25 year old male student of Environmental Governance, with an academic background in political science, and a current interest in business studies and sustainability. The research was conducted in the US. The researcher had no previous experience in doing research in the US, but has been in the US for recreational purposes in the past. This improved his understanding of the American culture. Subjectivity played a role in his convictions about sustainability. To reduce this bias, respondents were asked what their conceptualization of sustainability was, which sort of calibrated their answers. The internship with RenewThink facilitated attendance of around ten conferences and network events to improve understanding of cultural and behavioral norms in the business realm, as well as manufacturers in specific. It also enhanced the understanding of the concept of sustainability in the local context of Massachusetts.

Chapter 4. Results

This chapter will present the results. First, the analysis of EI radicalness will be conducted, after which three EI clusters are identified. The second paragraph focuses on exploratory learning and will shed more light on supplier, customer, competitor, and advisory interactions. The third paragraph continues with an analysis of transformative learning, looking at internal knowledge management processes and organizational structure. The subsequent paragraph directs attention to exploitative learning, the final learning process of AC. This will consist of an analysis of strategic fit between the innovation partners. Finally, paragraph 4.5 identifies the perceived drivers and barriers of EIs and sees how governmental interactions play a role in driving radical EIs.

4.1 EI radicalness

The data regarding EI radicalness are summarized in Table 13 on the following two pages. The cases are enlisted in a chronological order, referring to the moment the interviews were conducted. For each of the four aspects a bullet point summary is provided, trying to keep words to a minimum to enable the reader to compare aspects and cases at one glance. The full overview of qualitative data, including direct quotations, supporting the summary is presented in Appendix C.

Qualitative analysis of radicalness of innovation cases					
		Internal radicalness		**External radicalness**	
		Technological impact	*Technological uncertainty*	*Market impact*	*Market uncertainty*
A	Canopy LED Light (ILT)	- Component change. - ILT does only final assembly. - Very few employees affected by the new product.	- No learning/ training required, only some instructions to assembly workers.	- Industry already makes these lights, but ILT focuses on retrofits which is a new approach.	- Indirect customer relations. - Governmental rebates provide incentives to buy Canopy Light.
B	Hybrid UV press (CP)	- New machine, replaced two existing machines.	- Supplier training, six weeks, to understand technical operations.	- Technology is novel (3-4yr old) - Close monitoring of competitors enables CP to see the "bumps to come out".	*Not applicable*
C	Klear Can (Kortec)	- Design engineers main players in IP/product development. - Manufacturing not so much: co-injection technology was already in-house.	- Engineering knowledge was already in-house: NPD creativity came from internal design engineers. - Joint development with Kuraray regarding materials.	- Unique product.	- General market demand was gauged. - Still needed to convince suppliers of this (latent) demand.
D	Remote Phosphor technology	*Excluded case*	-	-	-
E	Mercury-free surgical lighting (LuxteL)	- Had to "totally redesign the product".	- Joint development with supplier, an electronic company.	- Market was oblivious, competitors didn't do it, but other industries did. -Regulatory trend towards mercury-free products.	- High: market was oblivious. - Product was same in fit, form and function, but had to persuade customers to use mercury-free.
F	Brazing furnace (LuxteL)	- New machine. - Three (of total five) employees were slightly affected by the change.	- Supervisor wrote a manual based on earlier experience with the machine. - The two other production workers read the manual.	- Bought it second-hand online. - Furnace was introduced on the market around 20 years ago. - "Too many people are buying new, which isn't even necessary."	*Not applicable*

G	Dry tenter frame (DK)	- New machine, replaced two other machines. - Operation of new machine was different. - Production team (5 persons) needed to learn about operation.	- Supplier's sales representative gave presentations and facilitated a visit to see the machine in operation. - Machine builder provided a trainer for a couple of weeks.	- Brand new machine, but technology was not brand new.	*Not applicable*
H	Sewing machine (ASC)	- Change involves automation of ten employees' jobs, who need to be re-skilled. - The new machine replaces two welders and ten sewing machines.	- Joint development (4 years).	- Uniquely developed for ASC	*Not applicable*
I	Biodegradable plastic coffee cartridges & valves (Urthpact)	- Design engineers are actively involved. - Manufacturing not so much: same machinery used, but different settings.	- Joint product development with customer and resin supplier.	- Development of entirely new product.	- Customer comes to Urthpact and is actively involved in the innovation process. - Little uncertainty due to a close customer within parent firm.
J	Manual low-flow faucets (Symmons)	- Component change.	-No training needed, just bought different flow restrictors from new supplier.	- Competitors were already down this path. Symmons followed.	- General market trend, partly through California drought.
K	Lead-free valves (Symmons)	- New raw material which affected the whole manufacturing team. And to a lesser extent also the design team.	- Some informal interactions preceding the acquisition of machinery. - Formal training (3-4 days) by tooling company.	- Competitors were already down this path. Symmons was probably the last one in the market.	- Regulations required Symmons to go lead-free. No other options.

Table 13: An overview of the radicalness of EI cases.

Following Table 13, the cases are clustered into three groups, based on an aggregate radicalness level. This is done in a way that the relative distance between the cases is as constant as possible, as explained in paragraph 3.3.1. This leads to Figure 8, below.

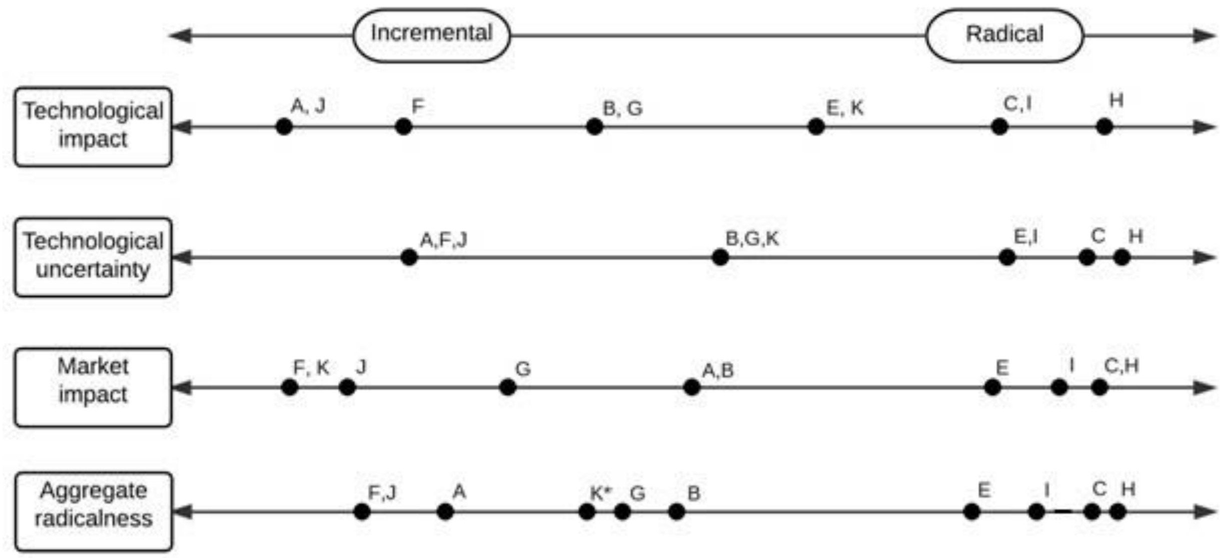

Figure 8: Schematic representation of radicalness of innovation cases.
**=There is not much variation between the different radicalness values except for Symmons' lead-free valve process (K). It is ambivalent, because they were forced to innovate due to regulations and were the last on the market to do so. Therefore they score very low on market impact. However, internally the operations have change more radically which results in a centered aggregate score.*

As one can see, the ultimate radicalness is an aggregate of only three sub-concepts. The concept of market uncertainty is excluded from the analysis because it is only applicable to product innovation. When developing a new way of production, like ASC for example, it does not matter how the market responds because it the change is directed at internal operations only.

When aggregating the scores, ten of the eleven cases score consistently over the three scales of radicalness. A,F and J are clearly on the left side of the spectrum, whereas E, I, D, C, and H are clearly radical innovations. The only ambivalent case is Symmons' development of lead-free valves (case K), as its internal radicalness is quite high, whilst its external market disruption is extremely low. In Par. 3.3.1 it was stated to exclude ambivalent cases. However, as data are valuable, it is decided to include case K. During the different steps of the analysis, case K will be discussed as if it were part of the intermediately radical cluster. However, during the interpretation, it shall be marked as ambivalent, so that it does not reduce the research internal validity. Table 14 presents the clustering of EI cases.

Cluster	Case(s)
Incremental EIs	F, J, A
Intermediate EIs	G, B, K*
Radical EIs	E, I, C, H
Excluded cases	*D, L, M*

Table 14: Clustering EIs.
** K is an ambivalent*

4.2 Exploratory learning

First, a brief overview of the different KIs is presented. Minimal verbal qualitative data are presented in a table, whereas radar charts enable the reader view and interpret these results at once glance. Subsequently, the presentation of the results of the independent variables of relative absorptive capacity are presented per knowledge source. So first, the roles of the suppliers in the adoption process are presented (Par. 4.2.1), then the customers (Par. 4.2.2), competitors (Par. 4.2.3), and finally the advisory organizations (Par. 4.2.4). Per source, we start with the incremental EIs, followed by the intermediate cluster and finally the radical EIs. Some descriptions of the interactions are presented, followed by a short analysis per cluster, to identify similarities and differences. At the end of every source interaction conclusions will be drawn in which incremental and radical EIs are compared.

Overview of knowledge interactions

Please see below the different KIs that manufacturers engage in. The three tables correspond to the three clusters of radicalness. Each KI is summarized in a few words. These words try to capture as much of the data as possible and concern relationship characteristics (i.e. frequency and formality of interaction) and describe the form of interaction.

Incremental EIs: external source interactions			
	F - LuxteL furnace	**J – Symmons faucets**	**A - ILT**
Supplier	Transaction	Transaction	Formal ad-hoc, incl. some design services
Customer	-	Indirect trend identification	Direct demand
Competitor	Monitoring	Bought competitor's product to learn	Monitoring
Advisory	-	-	Project-based
Regulatory	-	Restrictions on logo use	Rebates/technical standards

Table 15: Knowledge interactions with external sources for incremental EIs.

Intermediate EIs: external source interactions			
	G - DK	**B - CP**	**K* - Symmons valves**
Supplier	Training, and facilitated monitoring of existing technology.	Training	Training, formal, ad hoc
Customer	-	-	Prototype feedbacks
Competitor	Monitoring	Friendly consultations	Bought competitor's product to learn
Advisory	-	-	-
Regulatory	-	-	Prohibition

Table 16: Knowledge interactions with external sources for intermediate EIs.
**=ambivalent case*

Radical EIs: external source interactions				
	E – LuxteL (mercury-free)	**I - Urthpact**	**C - Kortec**	**H - ASC**
Supplier	Joint development	Joint development	Joint development	Joint develpm't
Customer	-	Joint development	Direct demand	-
Competitor	-	Cross-hiring	Tradeshows	Tradeshows
Advisory	-	Informal	-	Project-based
Regulatory	Quarterly reporting	Restrictions	Restrictions food safety	Grant

Table 17: Knowledge interactions with external sources for radical EIs.

Based on the quantification procedure explained in paragraph 3.3.2 (see Table 11), this leads to the following radar charts. The radar charts show that for radical EIs, much more formal and frequent interactions are required, especially with suppliers.

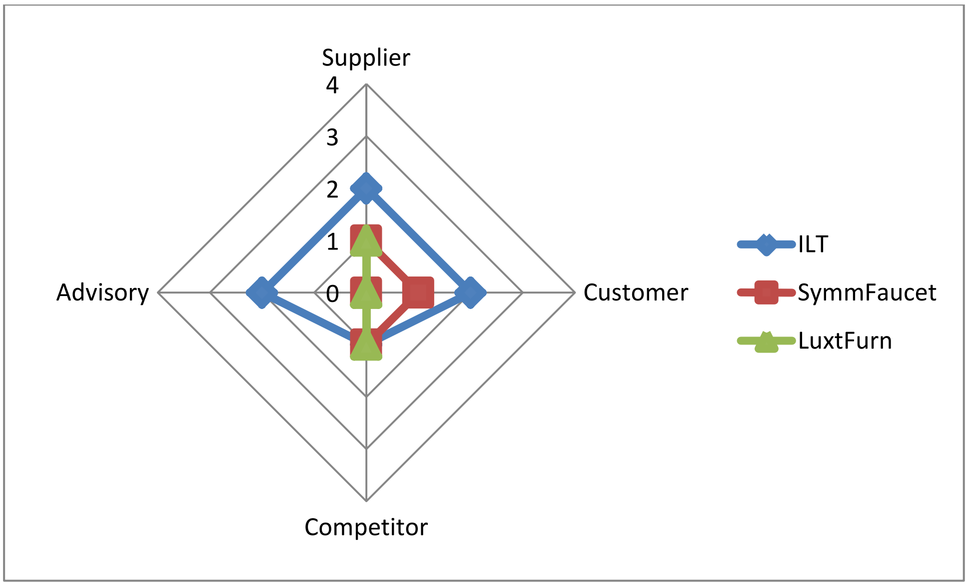

Figure 9: Intensity of knowledge interactions of incremental EIs.

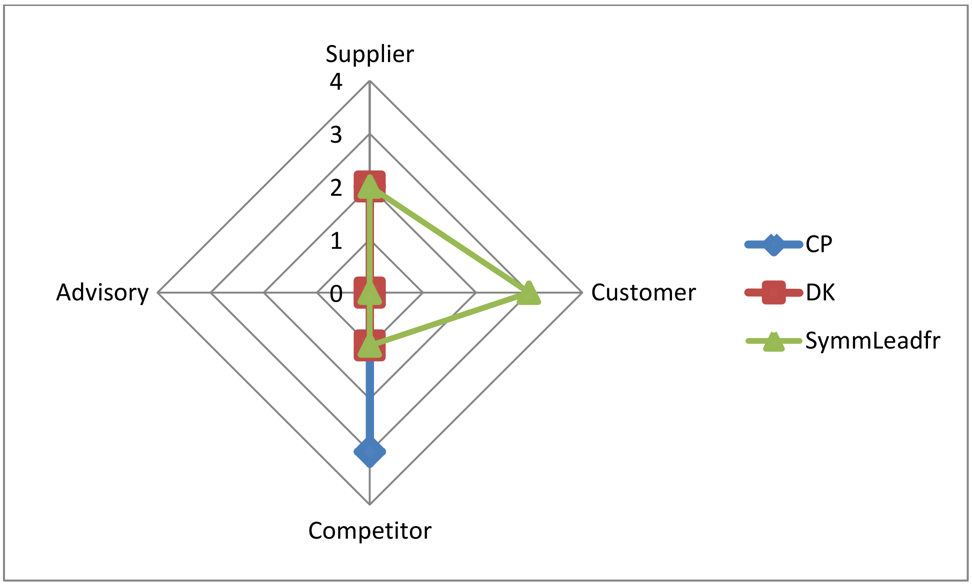

Figure 10: Intensity of knowledge interactions of intermediate EIs.

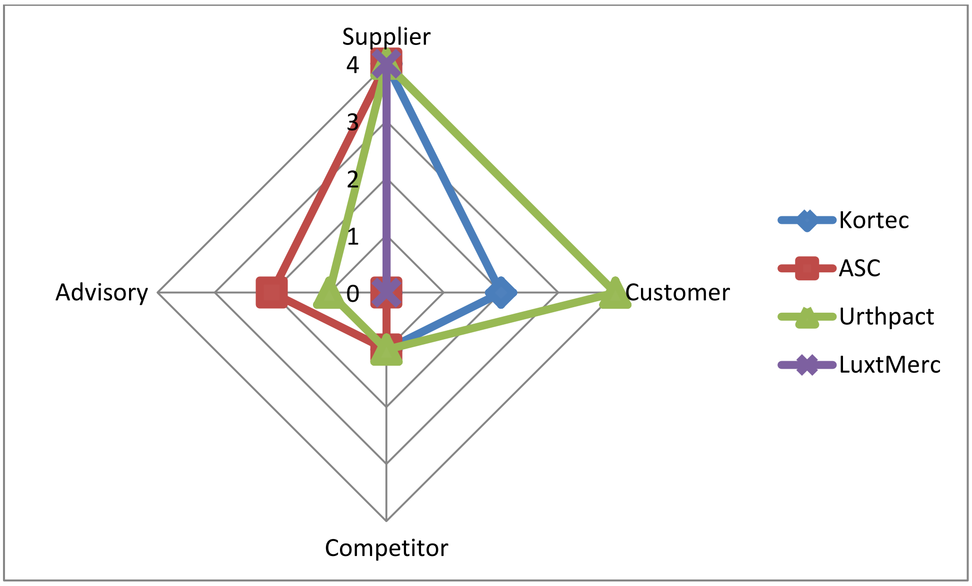

Figure 11: Intensity of knowledge interactions of radical EIs.

4.2.1 Supplier interactions

> *"We didn't know new power supply manufacturer very well. I mean, we had trust in the distributor, and we know the power supply manufacturer from the name as a reputable company, but how to communicate and how to really interact..? Sometimes he didn't know the questions to ask necessarily. So I think it would have been more effective if we had had better communication with the manufacturer."*

Pete Couture, Director ILT, on the relevance of communication in new supplier relations (Couture, Interview, April 2, 2015).

Incremental EI cases

Descriptives

ILT possesses some basic knowledge about lighting products and components (including LED light, power charge, housing), but for specialized knowledge, it engages in long-term partnerships with larger-sized electrical components distributors. These have more technological knowledge about electrical components, about the latest technology and employ very knowledgeable application engineers. The distributors provide a gateway mostly for technological knowledge, but also for market knowledge, as they are dealing with hundreds of customers like ILT. Although interactions consist of formal transactions, the distributor's application engineers are also useful the design phase of new product development, as was the case for the Canopy Light. They meet a few times during such development projects (Canopy Light development took eight months). New product development (NPD) is characterized by many design decisions and it is thus easy to miss relevant information. Knowledge is mostly codified, although it takes face-to-face discussions to make sure the best alternate components are applied in an optimal way. Knowledge is not very dependent. ILT's assembly workers need to know which component to use, but "the marketing guy couldn't care less". ILT highly trusts and leverages their distributors, although for the Canopy Light, a new Chinese supplier provided the power charge. ILT trusted the supplier, based on a third-party manufacturer's reputation. However, communication was sub-optimal: "They didn't know the questions to ask, necessarily" (Couture, Interview, April 2, 2015). The supplier made a design change that ILT didn't know about, leading to undesired outcomes in the prototyping phase. ILT believes that more direct communication, especially with the Chinese supplier's representatives in California, would have benefited the development process.

LuxteL acquired a brazing furnace from a second-hand dealer. It was an internal decision after which one employee went on the web to look for something suitable. He chose this machine, because he had previously worked with it at another company. No knowledge was exchanged in the acquisition process. It was nothing more than a transaction.

In developing the low-flow faucets, Symmons needed a different flow restrictor and a housing to fit into. A supplier in Maine was found after a couple of guys went on a trip to look for the right components. Implementing the new flow restriction "was not that big of a deal" and Symmons appeared to be fully aware of the necessity to innovate (Kinney, Interview, May 29, 2015). Knowledge was thus more or less already internal and also not very dependent or complex. Symmons possessed basic and specialized knowledge about what it specifically needed and how to implement it. The cognitive distance with the supplier in Maine was thus negligible. The relationship constituted a formal transaction.

Analysis

When comparing the above incremental cases one has to be especially cautious, because of the constitutive differences among them. Both ILT and Symmons entail a product innovation at the component level, whereas LuxteL concerns a process innovation. Symmons and LuxteL are both mere transactions, where hardly or no knowledge was transferred. ILT concerned a product development process in which KIs were far more important.

Firstly, in all incremental EIs, interactions involve *formal transaction-based interactions*. This seems logical as manufacturers can hardly do without suppliers. Whether suppliers exert influence in the adoption process is different. For LuxteL, it was a complete internal decision, where no suppliers were consulted. This is due to a sufficient internal knowledge base. No extra knowledge was required for the employees to understand the operation of the machine. Moreover, this was a second-hand deal, as opposed to creating something from scratch. Sometimes suppliers provide training as part of the acquisition of big pieces of machinery (see DK and CP). In this case, there appeared to be no services like this, perhaps because it was arranged by a second-hand dealer.

Secondly, regarding exploratory activities, all three manufacturers scan the market to find the right needs. All three use the web to do so, but Symmons and ILT additionally use existing relations to inform them. Symmons even went on a site visit to see if the product met their expectations, whereas ILT has long-term partnerships and high levels of trust in the suppliers' capabilities.

Intermediate EI cases

Descriptives

Within the intermediate group there is Draper Knitting and Colonial Printing and their acquisition of new machinery. Here, we also direct our focus to Symmons, the ambivalent case.

Draper Knitting acquired a dryer from a South Korean machine manufacturing company. One DK employee was appointed with the task to "hunt down potential machine manufacturers" (Wedge, Interview, May 5, 2015). As DK is pretty big in the 'Made in the USA'-market, it ideally wanted to buy American, but this proved too expensive. Additionally, the market is quite small, so narrowing down was fairly easy and soon the South Korean manufacturer was found. Some salesmen came over to do a presentation. DK's production manager flew to South Korea and looked at a few things. It comprised a formal transaction, which included training on the machine's operation. The trainer stayed "a couple of weeks". As it was a big investment, DK needed to make sure it could rely on the supplier. Therefore, "we evaluated everything, the technical expertise and we looked at the number of machines there were out in the field, which is one of the important things. We talked to people that are using their equipment now, and asked about how they responded if there was a problem." (Wedge, Interview, May 5, 2015).

Colonial Printing entails a very similar situation. CP acquired a hybrid UV press from Komori. CP possesses basic knowledge of printing services, but is not a press manufacturer. Driven by price, they looked at possible machines to buy, but "it's not like going out to buy a car" as the market is very small. Komori was preferred over Heidelberg (the "only one real other competitor") due to previous experiences with Komori: "[W]e were tight with the manufacturer (Komori, red.). So that obviously gave us the best deal, we knew their equipment the best." (LaValla, Interview, April 27, 2015). It didn't take long to decide on a transaction. Komori sent a trainer, who stayed at CP for six weeks to mechanically train the production staff. The trainer showed them the daily operational activities, but also how to replace rollers, deal with the ink and other kinds of problem-solving. Knowledge was quite dependent, as the whole Warwick production team needed to understand it. The investment could have been done four years earlier when the technology came out. However, this was not done, because it was reliant on the existing machinery more than nowadays.

Internally, Symmons' development of the low-lead valves was quite radical, but externally very incremental, as Symmons was the latest on the market to adopt it. The knowledge base of Symmons is quite technical, ranging from product design engineering to manufacturing process engineering and also some marketing capabilities. It definitely has basic knowledge of manufacturing processes, but is more specialized in other materials than stainless steel. Therefore, Symmons collaborated with tooling companies to get the right machinery. Symmons does employ a tooling engineer, but its skills and capabilities were insufficient to cope with the change. He, as well as the manufacturing engineers needed to be educated. Tooling companies provided training for three or four days and helped implementing the new machinery. The knowledge is quite tacit, as the machines "weigh tons, you can't just move them around" and they need to be debugged (Kinney, Interview, May 29, 2015).

Analysis

The three cases show many similarities. First of all, the interactions are all *formal transaction-based* and include on-the-job *supplier training*. The knowledge is quite tacit, as machines require debugging and specific settings. Also, the non-daily routines needed to be explained to the personnel. Suppliers possess specialized technological knowledge, whereas the manufacturers do possess a fair amount of basic knowledge regarding the technical operations. This optimal cognitive distance increased exploratory learning.

All companies engaged in market scanning. DK and CP scanned the market actively to see what would get them the best deal. In both CP and Symmons, trust played a role in the final selection process, whereas for DK price was more decisive. It interacted with the supplier in a back-and-forth sales process to make sure the new machinery could live up to the specified requirements. Firm strategy also plays a role in deciding what to buy, as CP has an active environmental strategy and was purposively looking for more efficient machines. In contrast, DK was triggered by dysfunctional previous machines that needed to be replaced, so it was more a quality thing.

Radical EIs

Descriptives

To develop the Klear Can, Kortec collaborated with two noteworthy suppliers. Kuraray supplied a crucial barrier material that keeps the contents preserved longer. Milliken supplied clarifying agents to make plastics transparent. General other suppliers were suppliers of PP, but this is an "off-the-shelf" product, so they were not influential in the EI adoption process. Kortec's knowledge base consists of specialized knowledge of plastics molding, and some basic knowledge about plastic as a chemical substance, but Kortec does not employ chemists or material scientists. Kuraray is an innovative chemical manufacturer, whereas Milliken is specialized in additives for plastics. Kortec needed to convince Kuraray of the market potential which took some effort. In return, they provided chemical knowledge and developed the barrier material. In both partnerships, a formal business deal was agreed upon. The interaction with Milliken constituted a transaction, whereas with Kuraray entailed a joint development project that resulted in a structural partnership. This partnership is formal, including monthly videoconferences and annual senior management meetings, although with an informal touch: "Although there is an agenda, the real agenda is to remain friends".

In designing two new mercury-free lighting products, LuxteL collaborated with an electronics company from California who helped them developing the electronic board. They were found through the web. It was a formal, joint development project, but initiated by LuxteL. As is common with joint development projects, knowledge is quite tacit and some design problems occurred in the process, but not more than normal. It especially required interaction in the beginning of the project, where the electronics company would show alternative, cheaper or more efficient designs.

Driven by a lean six sigma strategy, ASC wanted to automate ten sewing machines and sought help from Province Automation in Maine. They entered a formal deal, which resulted in a successful, but "rocky" four year development process. Province Automation is an expert in automation processes and mostly works with rigid materials. It also has some experience in the medical industry. ASC is an expert in producing surgical cotton-based (i.e. non-rigid) products. The relation was initiated by ASC, whose president had worked with Province Automation before. The development was more of an invention from scratch, as ASC came to the supplier with a question: "Can you make this? It was something that did not exist yet.". Knowledge was thus highly tacit and ASC representatives went to Maine once a week to discuss progress on the machine. The new sewing machine replaced ten production workers, who will be alternatively employed. It is unclear how many people are needed to operate the machine.

Urthpact collaborates with PLA resin supplier DaniMer Scientific to develop new biodegradable products. Urthpact is a spin-off of Innovative Mold Solutions (IMS), which is a plastics molding company with a high engineering core, and has a lot of expertise in plastics molding processes. Due to the newness and particularity of biodegradable plastics, it did not have an internal knowledge base on how to work with those materials. Urthpact looked for suppliers with similar corporate values (e.g. sustainability-oriented, innovative) and found one in DaniMer, who are specialized in degradable plastic resins. Knowledge about molding PLA-based resins is highly tacit: "You can make 100% PLA, but you can't mold that, so it needs a formulation to be able to mold it. And every product, depending on the geometry, how the mold's made can require a unique combination." Therefore, collaboration is high and intense, with weekly phone calls to discuss resin development and monthly visits to evaluate prototypes. The knowledge is quite dependent for the design engineers, but less so for Urthpact's process engineers, as "molding machines operate in a very similar way".

Analysis

All of the supplier interactions with radical EIs concern *formal joint development projects*. In the case of Kortec, the knowledge provided by Kuraray was crucial and their EI would not have existed without Kuraray on board. Similar is the relation between Province Automation and ASC, where knowledge was extremely tacit. Knowledge is relatively very tacit in radical EIs, because they are innovations that have never been executed before. ASC came to Province Automation with a general idea, but had no specific ideas or requirements on how to start doing it. In a similar vein, Kortec needed to convince Kuraray of the Klear Can's market potential, but it had some specific requirements what the plastic needed to do. Notice the shift from almost fully unidirectional relationship in the case of supplier training (CP and DK) to a more equal interaction with joint developments of ASC, Kortec and Urthpact. The knowledge bases of the innovation partners are quite similar, but not identical: where the cognitive distance between ASC and Province Automation was high, the distance between Urthpact and DaniMer was considerately lower.

Conclusions on supplier interactions

In comparing the three EI clusters, there are some interesting conclusions to denote. All EIs require supplier interaction, but only radical EIs are the result of an *intensive formal collaboration* or *joint development*. Such interactions are structural and occur frequently due to the newness of the innovation, the knowledge tacitness and the technological challenges arising in the process. The intermediate cluster is characterized by quite tacit knowledge exchanges in the form of *supplier training*. Incremental EIs are developed based on *transactions* where knowledge is *not necessarily* shared, although this was the case for two of the three incremental cases.

Trust is important in selecting the supplier regardless of how radical the EI is, but still needed to be built for radical EIs, as these concerned completely new interactions. For example, Kortec had an extremely new idea and could not rely on existing partners to develop this. It is therefore likely that interactions with existing suppliers tend the manufacturer to look into the existing possibilities, rather than out-of-the-box thinking applied by Kortec.

Innovation type seems to be correlated as well with supplier interactions as supplier training was the case for process innovations, whereas product innovations were developed with supplier interactions, some closer than others.

In all instances the suppliers provided technological knowledge, except for LuxteL's brazing furnace. In case of the radical EIs, technological knowledge also flowed from the manufacturers to the suppliers. Kortec also passed on market knowledge to Kuraray as they needed to convince them of the Klear Can's market potential. These interactions are thus more equal. On average, the more radical an EI is, the more intensive supplier interactions will be.

4.2.2 Customer interactions

Incremental EI cases

Descriptives

ILT's customers are convenience and grocery stores, as well as hospitality companies, such as hotels. ILT employs a marketing person and has some knowledge of the market trend. For example, it did a customer survey to see what fixture the Canopy Light needed to fit in, because it is a retrofit. However, ILT does not possess knowledge on what (a large number of) customers want specifically. Therefore, it teams up with energy service companies (ESCOs), which operate as third-parties between ILT and the end consumer. ESCOs provide ILT with very specific market information, such as "what the fixture needs to do [...] how we design it, what power level, what light output" (Couture, Interview, April 2, 2015). This information is very valuable for ILT: "So when we're thinking of a new product, we go to key ESCO partners that we know are intelligent, that have a higher level of sophistication to be able to get us back that market data. Market information drives what product we're doing." (*ibid.*, 2015). Regarding the Canopy Light, structural meetings with key ESCO partners provided a tipping point for ILT to calculate a business case. Because ESCOs are picky on energy efficiency (due to the rebates they receive), ILT does not want to make a mistake in the design process, which is why they meet quite regularly: "[W]e're always going back and talking...we actually put the project on hold for a little bit, to go back in and get additional feedback." (*ibid.*, 2015). Apart from the ESCOs, ILT sources market knowledge by attending conferences from industry associations, like convenience store and petroleum marketing associations. ILT is not a member of, for example, LED lighting industry associations.

LuxteL's acquisition of the second-hand brazing furnace did not involve communication with customers.

Symmons' development of low-flow faucets did involve a little market research. Symmons' marketing department conducted a short survey to see which faucet designs were preferred. The survey was aimed to illustrate market demand and was conducted at retail and commercial customers. In general, after the business case has been put together and when the design phase takes off, there is a routinized checklist to see if all customer needs are fulfilled, which then determines a go or no-go. Furthermore, it is expected that prototypes will be tested by consumers as well, but this is an assumption, based on Symmons' prototype testing of valves (case K). Unfortunately, it is unclear whether customers have actually tested faucet prototypes, because valid data are lacking.

Analysis
Of the incremental innovators only LuxteL does not interact with customers, simply because customers are not affected by a change in the internal production process. Although based on only one case, it seems very logical that customers have no influence in the adoption of *any* process EI. The other two are more interesting to analyze, and entail product EIs. Both ILT and Symmons use customer demands in their product development, either directly through testing prototypes or indirectly by customer surveys. Symmons is a larger company and these processes are part of protocol. ILT works more on an ad-hoc basis with the customer in a sort of joint development role. ILT is more dependent on ESCOs and therefore highly values their data, which is mostly clear and codified. In both cases, communication with customers did not seem to lack in quality.

Intermediate EI cases
Descriptives
When Draper Knitting acquired the new dryer, no customers were involved. It is a process innovation that does not directly nor indirectly affect customers. The new machine could do very similar things as the previous ones, only it can now make wider fabrics. Nevertheless, DK is a company that is highly customer-driven. Customers are intensively involved in product development, because everything is custom-made. DK's main customers are fire services and outerwear companies, such as Patagonia. The product development cycle is generally long, due to both deep supply chains of specialized materials and to testing procedures.

Similarly to DK, Colonial Printing did not engage with customers, because "my clients have not seen a loss of service or quality" (Wedge, Interview, May 5, 2015). Customers were not asked for feedback, because they were not affected by the change. CP knows its customers well and with this press, it stayed within the same customer segment. If a process innovation results in the production of products that are directed at a different customer segment, *only* then market research would add value.

As described above, Symmons main customers are consumer retailers, like Home Depot, or commercial wholesalers, such as Ferguson. In the ambivalent case of the valves, five or six sales representatives distributed prototypes toward the end of the innovation process. A couple of clients tested it and gave additional feedback. Symmons has some organizational routines, such as verifying whether all customer needs would be satisfied before starting a NPD project. Customer needs are identified through market research by the marketing department. The knowledge from these studies is thus codified. The knowledge is probably not highly dependent, as it concerns feedbacks only at the very beginning, as well as at the very end of the innovation process.

Analysis

Again, customers have no influence in the adoption of process EIs (i.e. DK and CP). Symmons' adoption of low-lead valves is the ambivalent case, as it scored high on internal technological disruption and low on market disruption. As will be shown in Paragraph 4.5, the adoption of low-lead metals was purely driven (or even caused) by governmental regulation. It has to be admitted that, in theory, customer feedbacks could have been influential as well. Symmons does include customer feedbacks, but only at the very start (go/no-go checkpoint) and end (prototype testing) of the product development process. The knowledge exchanged mostly concerns market demand, although it might include some technological knowledge too, depending on the skills of the specific customer. For example, a facility manager of a hotel - hotels are also customers of Symmons - might be knowledgeable enough to comment on technical operations of the valves. This is however based on assumptions. Because Symmons keeps customer interaction to a minimum and with little power in the product development process, Symmons scores low on exploratory learning from customers.

Radical EIs

Descriptives

Kortec's core business is to transform glass or metal packaging into plastic packaging. This research concerns their standardized 'flagship' product: the Klear Can, which was developed based on informal customer demands. "The way the Klear Can was developed was by conversations with multiple different customers. [...] The case of the Klear Can, and that is why it is so revolutionary I think, is that we were having conversations at various trade shows and conferences with different customers and they are all saying basically the same thing: I want to replace metal cans with plastic cans." (Bennett, Interview, April 27, 2015). Apart from the standard Klear Can, which is under study here, Kortec offers custom-made packaging as well, which obviously involves more intensive and formal interaction. Typical customers would be packaging companies, as well as consumer brands like Perrier and Nestle. Working with plastics requires intensive interactions in which Kortec uses "customer's requirements to drive and develop the work". Knowledge is much more tacit: "In the field of plastics, we talk about PP, but there are probably over a thousand types of PP that you can try. The exact properties that the customers are looking for, we sometimes have to do some material development work in order to achieve what they require."(*ibid.*, 2015).

LuxteL developed the mercury-free surgical lights around twelve years ago. At the time, "the market was totally oblivious" about mercury usage (Beech, Interview, May 1, 2015). No customers were thus involved in the adoption process. Rather, after adopting the radical change, LuxteL had to convince customers to go mercury-free and buy their products. LuxteL does not belong to any trade associations for market knowledge, because their market is so specific.

The surgical patties that ASC produces are sold to American hospitals directly, with surgeons as end users, although for the international market, they are sold through a distributor. For developing the automated sewing machine, no direct interactions with customers took place. However, the new machine is a form of (indirect) response to customer feedbacks. “The newer machines for example [are developed] to reduce customer complaints and to meet demand. Yes, we factor that in and we go ahead and greenlight that machine.” Informal feedbacks are gathered through exhibits of for example, the American Association of Neurological Surgeons, the Congress of Neurological Surgeons, and the American Operating Room Nurses Society, as well as from sales guys or representatives in the field. Being a data-driven company, ASC’s marketing department highly values, quantifies and evaluates customer complaints. There is also a program called the ‘post-mark clinical feedback program’, a “sort of clinical study, which is done at different sites and customers follow a protocol and give a feedback based on that protocol.” (Piasio & Alouane, Interview, May 12, 2015).

Urthpact’s development of the coffee pads and valves is quite a classic product development process. San Francisco Bay Coffee Company (SFBC) was one of the first customers of the newly spun off Urthpact. “Their primary goal was to get something on the market that was bio-degradable. There are lots of technical challenges to that.” (Pousland, Interview, May 27, 2015). SFBC expressed its demands, and did not provide technological knowledge. However, Urthpact needed to make sure it was producing according to customer needs and these are ultimately quite uncodifiable. In general, Urthpact believes in collective innovation, which is a core value of the company, and is expressed in long-term partnerships with customers. To illustrate the partnership’s success, it is important to know Urthpact is opening a manufacturing facility in California, directly neighboring SFBC.

Analysis

Normally, Kortec would have intensive collaborations in the form of joint development projects for new products. However, in this case, it concerns a standardized product, which is a result of many informal interactions with customers at trade shows. Other than igniting the idea, customers were not involved in the process. The effects, though, of those informal interactions are large as Kortec decided to make it their flagship product and involves many employees. Although the market knowledge was clear and codified, the translation into operational knowledge was much more challenging. Technological knowledge was needed, which the customer couldn’t provide. The same is true for ASC, where some informal feedbacks and customer complaints led to a general need for automation. Urthpact is a typical case of joint custom-made product development, which is obviously an intensive interaction. LuxteL did not involve customers, because the market was not yet ready for it. This is a confirmation of a general logic that goes as follows: Customers have demands and can complain and demand improvements on existing products. However, this is always based on their current knowledge base, which is inherently incremental. Radically new products are (possibly) too distant from their world of imagination, so that they cannot feel deprived for not having it, and thus are unable to express a demand for it.

Conclusions on customer interactions

According to the data, customer KIs only occur in case of product innovations. This already seemed logical beforehand, but it is now confirmed. None of the EIs related to new production processes have involved customers in the process. Only ASC stated that the new sewing machine is an indirect effect of their strategy: being data- and customer-driven, but it is interpreted as a distant side-effect. Customer interaction was apparent in all but one case (LuxteL's mercury-free lights) where new products were developed, in different forms:

- Indirect formal feedback	- *survey, complaints*	(Symmons' faucets, ASC)
- Direct informal demand	- *conferences*	(Kortec, ILT)
- Direct formal feedback	- *prototyping*	(Symmons 2x, ILT)
- Direct formal demand	- *joint development*	(Urthpact, ILT)

Obviously, customer interaction will be more intensive when products are custom-made for them. This is only the case in Urthpact's collaboration with SFBC, but would, for example, also be the case in DK's custom-developed fabrics (which are not included in the analysis). Nevertheless, we can conclude that customer interaction is determined by the strategy of the firm. Does it provide customized services, or is it focused on producing high volumes? That is as different as night and day. It can thus be concluded that customer interactions do not affect product EIs' radicalness necessarily.

4.2.3 Competitor interactions

As the knowledge bases of the focal firm and its competitors are almost identical, or at least very similar, it is expected that exploratory learning from competitors has a high potential: it is easy to understand and recognize the value of knowledge, because competitors are facing the same issues. However, interactions with competitors will not occur as naturally as for example with suppliers and customers. Even more importantly, firms are expected to protect knowledge from competitors, as this might have detrimental effects for their competitiveness. Competitors will probably only interact when both parties see the benefits, for example when they are only partly in competition. In the following, an empirical analysis will be presented of the competitor interactions for the cases in the three clusters of EI radicalness, followed by some conclusive remarks.

Incremental EI cases

Descriptives

In general, ILT looks at competing firms to a certain point, to see what technologies are being developed, as well as which market needs competitors respond to. This regards no formal interaction, but ILT monitors competitors' websites from time to time. The lighting industry is stable, but more and more competing firms are specializing in LED lighting, especially in Massachusetts. As ILT is relatively small, it positions itself in a niche market, focusing on convenience stores and gas stations. ILT is aware that monitoring competitors' product portfolios, for example, is not very beneficial for EI radicalness, because it reduces the company's creativity or product originality: "We are small, we are niche, we have to come up with something a little more creative that solves a problem for our customer." (Couture, Interview, April 2, 2015).

LuxteL did not seek contact with competitors in the process of acquiring the brazing furnace. It was a purely internal decision and the company did not need advice from competitors. Also, LuxteL operates in "not a very big market, it's very specialized" with only one other competitor in the US and one in Japan (Beech, Interview, May 1, 2015). A highly specialized market makes it physically difficult to be on speaking terms with competitors. Besides, LuxteL is too small (i.e. five employees) to be a member of trade associations, which reduces another possibility to interact with full or even partly competing firms.

Although Symmons is the largest company of this study's sample, it is one of the smaller players in the plumbing products market. In order to get the new flow restrictor, Symmons looked at competitors, although this did not provide crucial information. All competitors used an identical type of flow-restrictor, so Symmons got the same one and would have probably ended up buying the same one even if they were not aware of the competitors' choice. Symmons never interacts directly with competitors: "you can't do that in this market" (Kinney, Interview, May 29, 2015). To see what competitors were doing, Symmons' marketing team bought competitors' products and went on a 'fact-finding mission' to see what components and materials they used and how it was packaged.

Analysis

The incremental innovators' interactions with competitors are limited to *indirect unidirectional information flows*, either from websites or by buying a competitor's product in retail stores. Characteristics of the industry seem to be extremely important in determining competitor interaction. In the plumbing market, this is just not accepted. It is a highly technological, knowledge-based industry, where firms often have patents to protect IP from others. Specialization of the industry is another contingency that affects competitor interactions. LuxteL and ILT operate in niches, and therefore, there simply aren't that many firms doing the same thing. Firm size is also delimiting opportunities to interact. LuxteL is here the typical case, as it employs only five persons, who have simply no time to engage in industry associations, or other knowledge sharing platforms. Finally, there is a weak indication that product innovations are better suited for competitor interaction than process innovations. Products seem to be easily publicly accessible (e.g. website, store), whilst production processes seem to remain internal, as is the case with LuxteL. It has to be admitted that this is only an indication, so no specific statements can be verified or falsified.

Regarding radicalness, it is interesting to dedicate extra attention to Pete Couture's quote regarding creativity. ILT often designs custom-made solutions, based on direct customer demand, after which a business case is put together to see whether the custom solution can be a structural part of the product portfolio. Couture thinks that looking at competitors' product portfolios decreases the opportunity to provide innovative solutions. Implicitly, he states that EI radicalness is negatively affected by competitor interactions. His rationale seems logical, as a true unique, virgin invention will definitely not result from competitor interaction, simply because it has not been done before. So it can be argued that ILT aims to be a radical innovator, although the Canopy Light itself was not classified as radical, mainly due to the lack of internal technological disruption.

Intermediate EI cases

Descriptives

Draper Knitting does not have many competitors. For sliver knitting - used for products such as paint roller fabrics - there is only Monterey Mills. Compared to them, however, DK operates in a small specialized niche focusing on protective fabrics for firemen's clothing and outerwear. Additionally, Monterey Mills is more high-volume production and less focused on custom-made products. DK sometimes meets with other competitors at trade associations, where they write technical industry standards. However, this knowledge has not been used in the acquisition of the dryer. Rather, the supplier of the dryer facilitated for a visit of a (partly) competing firm that used the same dryer, to see how it was running. The contact was initiated by the supplier, who operated as a mediator.

In contrast, Colonial Printing has close informal collaborations with its competitors. The president of CP is even close at a private level: "My biggest competitor in Rhode Island, him and his wife and me and my wife, we go down to Manhattan and spend a weekend in Manhattan the four of us. We are close enough to do that." (LaValla, Interview, April 27, 2015). This friendly relationship is possible, because they either compete "as friendly as possible", or don't compete directly (due to different geographical markets). Perhaps the president is biased, as he is not the sales person, although according to him neither the sales persons 'bang their heads'. CP interacts with its competitors indirectly through suppliers, and directly in case of specific technological needs.

Firstly, when the hybrid UV technology was released four years ago, CP and competitors were flown in by suppliers to look at the machine, at a sort of sales conference. Some competitors bought the press immediately, while CP waited a few years "to see the bumps come out" (LaValla, Interview, April 27, 2015). Competitors who did buy it at the time, were less reliant on their internal manufacturing equipment. In contrast, CP only possessed a few machines, so they waited until the prospected benefits would outweigh the investment costs.

Secondly, CP is able to call on competitors in case of specific technological questions, for example when machinery breaks down. The connectedness of the industry is strong and there is also a high sense of solidarity among competitors. Both factors facilitate competitor learning. "Some of my friends are much larger than we are, they are able to help the manufacturer, work with the ink supplier. Even till today there is only one ink supplier, so we all have the same ink. As far as the chemistry goes, we all have to buy the same chemistry. [...] But as far what we can do is... someone is on the leading edge of this and we are learning stuff and feeding it back to them." (LaValla, Interview, April 27, 2015).

Symmons does not interact directly with competitors: "you can't do that in this market" (Kinney, Interview, May 29, 2015). Symmons was definitely the last company in the market to adopt manufacturing with low-lead metals. Therefore, learning from competitors showed actual potential. Symmons "looked at our competitors' valves and how they've put it together and see how we can be more price-competitive" (*ibid.*, 2015). Symmons' marketing team bought competitors' products and went on a 'fact-finding mission' to see what components and materials they used and how it was packaged. They found that competitors used plastics for some parts, which is why they could sell it cheaper.

> *"This press is about three, four years old. So when it first came out, I waited for all the bumps and bruises to come out of it before I would jump in."*
>
> Joe LaValla (Colonial Printing) is aware of market timing and opportunities to learn from peers.

Analysis

The intermediate cases do not show many similarities in the way they interact with competitors. Both CP and DK are cases where big pieces of machinery were installed and suppliers facilitated training. CP is an extreme case as it has *strong informal interactions* with its competitors. This is directly related to industry contingencies. The printing industry is characterized by a dense network and strong senses of solidarity among firms. In contrast, the fabrics industry is smaller in size and within that market, DK operates in a niche. What seems to determine exploratory learning from competitors mostly, is what I call *market timing*, which refers to the moment of adopting an innovation relative to competitors. For example, Symmons was the latest adopter in the market and therefore it scored low on (external market) radicalness. In contrast, however, it was quite radical on the internal technological aspects, which is the reason why it was classified as ambivalent. The market timing facilitated for a fruitful learning process simply by looking at competitors' products and copying their solutions. The same is true for CP, which purposively waited a few years, so it could learn from competitors. It helps that CP has friendly relations with competitors. Friendly relations were absent in the case of Symmons and DK, so they had to learn from competitors *indirectly* by buying their product (Symmons) or through the supplier as a mediator (DK).

Radical EIs

Descriptives

Kortec attends some industry associations to identify other technologies, which could aid existing or future projects: "We belong to a couple of trade associations, the SPI, Society of Plastics Industry and the Rigid Plastics Packaging Group, a specific division within the SPI. [...] [T]here is kind of information that gets discussed and shared. Principally, most of what we do, what we gather about competitors, is done at things like trade shows and conferences, they make presentations, and you visit their booths." (Bennett, Interview, April 27, 2015). There are no formal interactions with competitors. To protect IP, Kortec possesses two patents related to the Klear Can specifically: on the co-injection molding technology, as well as on the structure of the plastic can design.

LuxteL did not communicate with competitors to switch to mercury-free surgical lights, because competitors were still making the products *with* mercury: "the law allows it, it's been grandfathered" (Beech, Interview, May 1, 2015). 'Grandfathered' means that manufacturers can produce old(er) technologies, as long as their existing in-house equipment is able to do so. However, they are not allowed to invest in new machinery to do the same thing. LuxteL disagrees with the loose legislation and started to develop mercury-free products regardless of the industry norm. Regarding the competitive landscape: "There are three producers of surgical lights in the world, we are number two. And we have about 10% of the market. It's not a very big market. It's very specialized. [...] One [competitor] in Japan, and one in California. The biggest one is in California." (Beech, Interview, May 1, 2015). The fact that the market is so small does not facilitate for interaction either.

ASC did not communicate with competitors in order to develop the automated sewing machine. The machine was designed from scratch and completely unique, so it was unlikely that competitors had such a machine. Moreover, the competitive landscape of ASC consists of a big multinational (J&J) and other larger firms, like Cardinal and Metronics. For them, neuro-patties represent only a small market. ASC is the innovative leader in this product segment. "We are certainly in the US the only company out there that aggressively develops and promotes neuro-surgical patties." (Erik Piasio, Interview, May 12, 2015). In general, ASC does meet with (partly) competing firms of the medical device industry in associations such as MassMEDIC and AbaMed. They have meetings quite frequently to discuss best practices, benchmarking and problem solving.

Urthpact did not have any interactions with competitors in developing the coffee cartridges and valves. However, Urthpact and its parent company IMS are based in Massachusetts for a reason: it is the plastics hub of the US. "This area in the country is sort of where the manufacturing of plastics started. So there's a lot of plastic companies in this area." (Pousland, Interview, May 27, 2015). This facilitates for a cross-hiring of employees among competitors. NYPRO is a big competitor, which is geographically speaking very nearby. Some of IMS/Urthpact's people have worked there, and vice versa. The benefits of this are to "keep a pulse on what's going on" in the market as well as in the technology domain (*ibid.*, 2015). It is quite valuable because the competitive landscape will be much different in three to five years from now. Now Urthpact has none or hardly any competitors in the US. There are bigger competitors in Europe, but Urthpact's market is still domestic up to now.

Analysis

All of the radical EIs presented here are technologies that are unique on the market. Therefore, it is no surprise that no competitor interaction took place to develop the EIs specifically, as simply no competitors were doing the same thing. Even on the contrary, competitors need to be deterred from interacting with the radically innovating companies. That is why Kortec patented its technology and product design. Urthpact has no opportunity to learn from competitors in the US, although it admits it could collaborate with European companies who are more advanced. However, they abstain from doing so, because of the discomfort of dealing with the distance as well as potential import regulations. Urthpact finds itself in a comfortable competitive position already, although it is important to gauge trends, which they do through the web or also - like Kortec and ASC - by attending trade associations' meetings. The overall goal of this, is to see what competitors are doing and how to position oneself in the market. LuxteL does not do so, because of its limited size.

Conclusions on competitor interactions

After assessing the different competitor interactions five conclusions can be drawn. One, in comparison to suppliers and customers, interactions with competitors occur much less frequently. Reasons for *non-interaction* are the protection of IP (e.g. Kortec), the fact that there are not many competitors in the area due to specialized industries (e.g. ASC, LuxteL) or operations in niche markets (e.g. ILT, DK, Urthpact).

Two, except for LuxteL, every manufacturer engaged in *indirect informal interactions* with competitors in the form of monitoring competitors' websites, at trade shows, or buying competitors' products. Firms monitor their competitors' behavior to feedback this into their own strategies. For example, Symmons saw that some components of a faucet were made of plastics, rather than expensive metals. Especially for firms in niche markets this is important, because their customer segment is relatively small. Lastly, LuxteL behaved aberrantly, because its market is highly specialized and because it employs only five persons and therefore has no time or priority to interact with competitors.

Three, *direct informal interaction* only occurred in one case (CP), but prove very effective. The fact that the printing industry is very connected and that CP does not operate in a niche allow for close informal interactions with 'friend-competitors'. Interactions concerned technological information about manufacturing equipment.

Four, and now turning to EI radicalness, it is found that there are *no direct interactions* that contribute to the development of radical EIs. Developing an extremely radical innovation almost by definition is a unique innovation that does not yet exist. Therefore, it does not make sense to ask competitors about this, simply because they haven't faced the same issue. On the contrary, being a late adopter of an innovation (e.g. Symmons' low-lead valves) makes it more fruitful to learn from competitors. CP has even done this purposively, as it waited for competitor's feedback on the HUV press.

Finally, innovation type does not seem to correlate necessarily with competitor interactions. Informal interactions are committed for the sake of both product and process innovations, although it is likely that knowledge on product innovations is more easily accessible by competitors, whereas production processes are likely to be kept internal.

4.2.4 Advisory interactions

Incremental EI cases

Descriptives

In the development of the Canopy Light, ILT hired an external thermal engineer, which is in line with their general hiring practices. ILT hires consultants mostly for technical design issues, to complement its limited engineering staff: "The consultants are more on the actual design, also for the Canopy Light. We will say to them: 'we want it to fit in this type of fixture, this size, this shape, these lumens, light output, power level, specifics'. And then, we work with the consultant." (Couture, Interview, April 2, 2015). ILT has a limited engineering core and includes a mechanical engineer and an optical engineer. However, for some issues a thermal engineer is required, but ILT is not able to employ someone on a permanent basis. Rather, it hires thermal engineers as consultants on an ad-hoc basis and this constitutes a formal interaction. ILT only hires consultants it can trust, either through direct previous experiences, or indirectly through referrals by partners. In the eight months development process of the Canopy Light, communication occurred monthly, and more frequently during crucial design phases. Frequent interaction is needed due to knowledge tacitness: "It's a lot of interaction, and a lot of step-by-step. And it needs to be a lot of interaction, because you're making design decisions constantly. You work as closely as you can, as time allows." (Couture, Interview, April 2, 2015). The new knowledge is quite independent, as ILT focuses on assembly, which requires less skilled labor. Finally, ILT said that in the past they used consultants to supply them with market knowledge, but they do not rely on it and, nowadays, they use the web to get that information.

The other two incremental innovators, Symmons and LuxteL, have not made use of external consultants or other advisories. For LuxteL, it was an internal decision and the required knowledge was not very tacit or dependent. Besides, there was already an employee who knew how to operate the new brazing furnace. Symmons and their low-flow faucets were also absent from advisory interactions, as Symmons knew perfectly well what to do and how to implement the new flow restrictor.

Analysis

It is difficult to conclude on the basis of only three cases, but what can be seen is that advisory organizations are included in the adoption process mostly for technical challenges. In case of ILT this is very straightforward: due to its limited size, it relies on external advisories. In the other cases, the adoption process was simply not very challenging from a technological knowledge point of view. Internal knowledge and experience resolved the issues sufficiently.

Intermediate EI cases

Descriptives

None of the intermediately radial EIs (CP and DK) and neither the ambivalent case (Symmons' low-flow faucets) have made use of external advisory organizations in the process.

Analysis

Both CP and DK faced technical challenges, which is an opportunity for advisory interaction. However, these EIs comprised the acquisition of machinery and technical challenges were already resolved by supplying partners Komori (CP) and the South Korean company (DK), in the form of on-the-job mechanical training.

Radical EIs

Descriptives

In the joint development with Province Automation, ASC hired some technical consultants to help with the challenge of automation. Province Automation is specialized in this, but has never worked with sewing machines. The technical consultants were specialized in sewing machinery. Additionally, because regulatory requirements are constantly changing and ASC exports to many different countries, ASC collaborates with regulatory consultants. ASC's Director of Quality Michael Alouane is "our in-house regulatory guy", who possesses the basic knowledge about regulations, but for "the heavy lifting and the expertise, we rely on outside consultants" (Piasio & Alouane, Interview, May 12, 2015). It is unclear if this happened specifically for the sewing machine.

Urthpact has "high collaboration" with technical consultants, to provide assistance with manufacturing processes (mostly molding). Unfortunately, there are no data available on how and why Urthpact relies on them, because Urthpact has a strong engineering core and possesses specialized knowledge about plastics engineering. More informally, Urthpact collaborates from time to time with both the University of Massachusetts in Lowell - who offer a plastics engineering degree and have a 'plastics lab' - as well as the Worcester Polytechnic Institute. Professors would then help Urthpact with a technical challenge they encountered in the process. No formal collaboration has rolled out of such interactions as of yet, but the added value of professors is that they are not only intelligent, but also very experienced.

Finally, of the other two radical innovators (LuxteL and Kortec) no elaborate analysis can be given. LuxteL did not make use of external advisories, whereas from Kortec no valid data exist.

Analysis

Both Urthpact and ASC rely on external consultants for technical challenges, while ASC also needs to inform itself on regulatory requirements. In both instances the knowledge was quite tacit and required face-to-face contact. It concerns manufacturing processes (sewing and molding) where machinery settings are important and it is all about trial and error. Also, both cases entail a unique development process, rather than acquiring a ready-made piece of machinery, that only needs to be installed.

ASC additionally relied on regulatory consultants to help them with intellectual challenges. These challenges are related to two industry contingencies. First, the medical sector is subject to strict regulations regarding hygiene, especially for surgical products designed to be in direct contact with the venous system of patients. Second, ASC operates in a very international market and regulations differ almost per country.

Finally, although valid data is lacking, it is assumed that Kortec did not need external knowledge from advisories, because it has a strong intellectual core with IP protected through patents. LuxteL did not need consultants, because of its internal knowledge base and an already close supplier relation.

Conclusions on advisory interactions

One finding holds that external advisories are only included if internal knowledge capabilities are insufficient *and* if no other structural or formal partner (e.g. supplier) is able to provide this extra knowledge. Seeking help from advisories is a kind of 'last resort' strategy. This is most likely the case for Urthpact, and a little bit for ASC as well. Urthpact has a large and specialized internal knowledge base, but still has high collaboration with technical consultants to help them with molding processes. This is probably due to unexpected challenges during production processes. ASC relied on consultants when it countered sudden problems in automation of sewing machines, as their supplier-partner did not possess that specialized knowledge, nor experience. However, ILT and ASC rely on external consultants structurally for common problems. They are not able to employ people on a full-time basis for regulatory knowledge (ASC) or thermal management (ILT). Size is thus an indirect determinant of advisory interaction.

Exploratory learning was perceived to be very smooth, as the cognitive distance between the manufacturers is quite optimal. Manufacturers knew what types of knowledge they needed and requested this plainly from a consultant, who without exception possessed specialized knowledge. Consultants are paid to transfer their knowledge in a way that it can be understood and implemented directly, which is beneficial for all three learning processes of relative AC. The relationships with consultants are without exception formal, ad-hoc collaborations. In controlling for innovation type, it can be concluded that advisories were used for product innovations (ILT, Urthpact), as well as for process innovations (ASC). It thus seems that advisories can influence both types equally well.

Regarding radicalness, we can conclude that knowledge from external advisories is not necessarily affecting an EI's radicalness. More so, using knowledge from advisories depends on the intellectual capabilities of the focal firm. A consultant will be hired in case the company is unable to resolve the, mostly technical, problem with its internal knowledge base. In all cases of external advisories, the influence of them is perceived to be effective and in one case even crucial (ASC).

4.3 Transformative learning

Transformative learning is the capacity of a firm to assimilate external knowledge. The more efficiently knowledge is disseminated through the organization, the better its transformative learning capacity will be. Efficient dissemination is needed in case knowledge is complex (i.e. tacit and/or dependent). Dissemination of knowledge is enhanced by an organizational structure in which information is communicated frequently and across different functional units. Job rotations and cross-functional interfaces aid this process. Whether an organization has a functional, a divisional, or a matrix form also affects its transformative learning capacity. According to a conceptual paper by Van den Bosch *et al.* (1999) a functional form has a high impact on efficiency of knowledge absorption, whereas both matrix and divisional forms have a lower impact.

> *"The employees have all been part of the company since a relatively long time, even the manufacturing staff. I would say we're probably high on the scale of cross-training just because of that. As we grow bigger, and we are seeing this kind of explosive growth, that's one of the things where we'd say: how do we maintain that? How do we maintain our agility to be able to jump on these new things, as well as keep a staff that is more broad-based versus a silo kind of organization. We don't want that."*
>
> Michael Pousland (Urthpact) on the dynamics between firm size, organizational structure, and transformative learning (Interview, May 27, 2015).

In assessing the influence of transformative learning on EI radicalness, a few steps need to be taken. First, a knowledge complexity check will be conducted for the EI cases. For example, in some cases the knowledge is not tacit and neither dependent, which makes transformative capacity redundant. Second, based on data from the interviews the manufacturers will be scored according to their capacities to engage in transformative learning (i.e. lots of cross-functional interfaces, little hierarchy, and a functional structure). Third, for the cases in which transformative learning is necessary, transformative learning capability and EI radicalness will be linked so that it would become clear if there is correlation between the two concepts.

Due to the comprehensiveness, the descriptions of the cases' organizational structures are represented in a table in Appendix E. Before checking the knowledge complexity of the cases, one important comment has to be made: firm size is a major determinant of transformative learning. Most companies of the sample employ between thirty and fifty people. Symmons and LuxteL are deviant, employing 300 and five employees, respectively. Therefore, the scale of knowledge transfer is much lower in LuxteL than in Symmons. Within LuxteL, only two persons needed to be educated, whereas at Symmons a whole team or department needed to understand how the machinery works. Because LuxteL is so deviant, it cannot provide any valid comparative insights and is therefore be excluded from analysis.

Knowledge complexity check

Please see below the check for knowledge complexity, based on data from the interviews (Table 18).

Case	Knowledge tacitness	Knowledge dependency	Knowledge complexity
A – ILT	*Low* –Mostly codified, some discussion is needed	*Low* - Just a component change, only assembly workers affected to a minimal extent	*Medium-low*
B – CP	*High* - It took two months of personal training to fully understand operations	*Medium* - Production team needs to know mechanical operation of the press)	*Medium-high*
C – Kortec	*High* - Properties of new barrier material were unclear, lots of design iterations	*Medium* - Klear Can is only a part of the Kortec's business, although six design and manufacturing engineers are involved	*Medium-high*
G – DK	*High* - It took a couple of weeks of personal training to fully understand operations	*Medium* - Production team needs to know mechanical operation of the dryer)	*Medium-high*
H – ASC	*High* – Lots of design interactions	*Low* – Only manager and Director of Quality involved, centralized	*Medium*
I – Urthpact	*High* – Lots of design interactions	*Medium* – Product development team is constantly involved	*Medium-high*
J – Symmons Faucet	*Low* – It was clear what to do and how	*Low* – Only new component	*Low*
K – Symmons Valve	*Medium* – Tooling companies helped making the change	*High* – Required whole new (settings of) machinery	*Medium-high*

Table 18: Knowledge complexity check.

Only when knowledge complexity scored 'medium-high' or 'high', it is assumed that organizational structure is beneficial to the implementation of EIs. Cases A, H, and J are thus excluded. The backing argument here is that a lot of cross-functional communication simply just would not matter in the respective adoption processes.

Scoring transformative learning capacity

Based on the interview data, all cases are scored low, medium or high for transformative learning, which results in the table below.

Case	Structure	Hierarchy	Cross-functional interfaces	Transform-ative learning
B **CP**	Separated geographically. Upper management in Windsor, CT, while production in Warwick, RI	*Medium* - Quite hierarchical	*Low* – "Does not happen as much as we should do"	*Medium-low*
C **Kortec**	Small organization with large skilled engineering core (70%)	*No data available*	*High* – Design and process engineers cooperate in projects	*(Very) good*
G **DK**	Functional – Arranged per product category	*Medium* - Decreasing, DK reorganized because too many supervisory positions	*High* – All employees wear different hats	*Good*
I **Urthpact**	Very flat, small organization with large skilled engineering core	*Low* – Very flat, agile organization	*High* –Close network of loyal employees, lot of cross-training, 'collaborative innovation'	*Very good*
K **Symmons valves**	Divisional – Production process steps are all separated	*High* – Large size company with multiple levels	*No data available*	*Low*

Table 19: Scoring transformative learning.

Linking radicalness and transformative learning

It is expected that manufacturers with a high level of transformative learning are better capable of implementing radical EIs. In figure 12 below, transformative learning capacity and EI radicalness have been juxtaposed on two axes. It becomes clear that the only two radical EIs that were dealing with a very complex external knowledge are indeed developed by companies with a high level of transformative learning. However, the data and method are insufficient to come to generalized conclusions. For one, intermediate EIs that required complex knowledge are also successfully adopted by companies with low or medium transformative learning capacity. It has to be acknowledged, though, that Symmons is the ambivalent case, regarding radicalness. Internally, the decision was very radical, but Symmons scores low on the transformative learning capacity. It could thus be a rejection of the expected relation between transformative learning and EI radicalness.

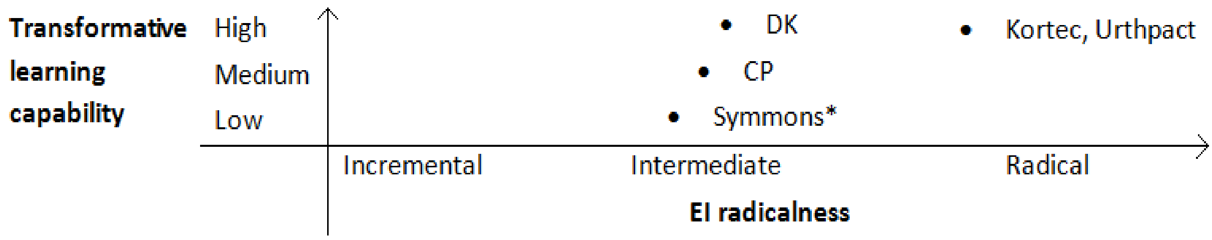

Figure 12: Relation between transformative learning and EI radicalness
**Symmons is the ambivalent case as it scores very high on internal radicalness and extremely low on external radicalness. Nevertheless, it is here clustered in the intermediate group.*

Conclusions transformative learning

Because the evidence is not very strong, it is very difficult to draw generalizable conclusions. However, the data do show that in case knowledge complexity is high, transformative learning is a necessary condition for the successful adoption of radical EIs. The reader should be aware that knowledge complexity is not necessarily high for radical EIs, as this depends on knowledge tacitness and knowledge dependency. Nevertheless, it should be denoted that this conclusion is not very valid externally, as due to limited data, it is quite likely that cases exist where transformative learning capacity is low and EI radicalness is high. This would then falsify the above-presented conclusion.

4.4 Exploitative learning

Exploitative learning is the process of applying new knowledge in order to achieve commercial objectives. Exploitative learning is enhanced when the student and teacher firm apply a similar strategy, or strategic fit. After gathering the data, it can be concluded that strategic fit did *not* play a role for solely transaction-based or informal relations. In an interaction where the manufacturer simply paid for a product (e.g. LuxteL's furnace, DK's dryer), it often does not matter what the values and strategies of the supplying firm are. This seems logical as in more intensive collaborations, such as joint development projects and structural, long-term partnerships the interests of the student manufacturers are more under influence of their teacher firms. As radical EIs are more challenging and require more intensive collaborations, strategic fit is expected to play a role only in the cases with intensive knowledge interactions. Therefore, the analysis of exploitative learning is limited to EIs preceded by intensive KIs (see Table 20).

Case	Supplier interaction	Customer interaction	Competitor interaction	Advisory interaction
A – ILT	-	-	-	Ad-hoc formal
B – CP	-	-	Friendly consultation	-
C – Kortec	Joint development	-	-	-
E – LuxteL	Joint development (*no valid data*)	-	-	-
H – ASC	Joint development	-	-	Ad-hoc formal
I – Urthpact	Joint development	Joint development	-	"High collaboration" (*no valid data*)

Table 20: Intensive knowledge interactions.

Strategic fit with suppliers

Kortec had an inventive idea but needed a plastic to have very specific qualities. They found chemical engineering company Kuraray, but as of yet there was no strategic fit at all, as Kuraray was not convinced of the potential: "'We don't think it's possible to have a plastic can that replaces metal cans. Therefore we don't want to work with you on this project'. So we had to convince them by introducing a few of our customers, who believed the technology would work." (Bennett, Interview, April 27, 2015). After all, Kuraray became convinced and the project took off. Bennett views Kuraray is a 'typical Japanese company' that sets long-term goals, rather than typical American companies, who only look at profitability of the next quarter. This fitted Kortec's sustainability strategy very well. Apart from staying in business, they try to remain friends as well. Kortec also collaborated with Milliken, but that company supplied 'off-the-shelf' products, so no intensive KI took place.

LuxteL also collaborated in a joint development with a supplier, but unfortunately no specific data are available to discuss here.

> *"At times, I'd say it was a rocky relation. [...] It got a little bit frustrating at times and he is a very good guy, but can be difficult to work with. At least from my standpoint, because we are two kind of different people, but we worked through it."*
>
> *"It was difficult because of our expectations and because it's a new machine. He is a smart guy and he is like an artist also. He has ideas, and those kind of people they need time. And we're manufacturers: we don't have time."*
>
> Piasio and Alouane (ASC) on the lack of strategic fit between Province Automation and ASC (Interview, May 12, 2015).

ASC teamed up with Province Automation, whom they knew through personal experiences. There was little strategic fit between the two innovation partners. The relationship was 'rocky' and "got a little bit frustrating at times and he is a very good guy but can be difficult to work with. At least from my standpoint, cause we are two kind of different people, but we worked through it. [...] He's like an artist also. He has ideas, and those kinds of people they need time. And we're manufacturers: we don't have time." (Piasio and Alouane, Interview, May 12, 2015). It has to be noted that the project was very new, and technologically challenging, but the total process took four years, which is very long. Nevertheless, the partners still managed to succeed - albeit with some help of consultants - and ASC was satisfied after finalizing the project.

Urthpact's commitment to innovation is shown by the company-wide value of 'collaborative innovation'. This is also expressed in the way they engage in partnerships with suppliers: strategically and long-term. To see whether the innovation partner fits strategically, Urthpact collaborates in a small project first. For example: "The resin suppliers we're typically partnering with are the ones that are kind of on the cutting edge of: 'Well, here's a new material we've been working with which is also green.' We don't want to work with companies who have been working with PP for fifty years." (Pousland, Interview May 27, 2015).

Strategic fit with customers

Urthpact is the only company that intensively engages with its customers in adopting an EI. At the time, IMS made the decision to spin-off Urthpact to be able to become more closely tied to its customer segment: "Our life science products tend to be very specialized, using plastics that are typically very resilient. [...] In the defense space, the parts are typically made to be indestructible, so they're not very interested in putting it in the soil and that it breaks down. [...] So it's a very different model that, as we engaged with San Francisco Bay Coffee, we started to realize: Wow, it's an entirely different model" (Pousland, Interview May 27, 2015). SFBC thus appears to be the constitutive customer on which Urthpact decided to transform its existing strategy, from 'durable' to 'sustainable'. The strategic fit between SFBC and Urthpact is thus very high and from Urthpact's side, no explicit complaints occurred in the joint development process.

Strategic fit with competitors

The only noteworthy competitor KIs are found within Colonial Printing, which engage in very informal and friendly relations. Strategic fit is to be regarded as identical, as printers face similar issues. LaValla could ask his 'friend-competitors' about mechanical issues and reviews of machinery. Due to their geographical differences, there is no barrier for cooperation, which is not the case for other manufacturers of the sample.

Strategic fit with advisories

Regarding intensive advisory interactions, only ILT and ASC require a deeper analysis. ILT relied structurally on outside technical consultants, and in specific on a thermal engineer. ILT's director attaches a lot of value to an overlap in strategy: "I wouldn't want to go to a company that's designing for aircraft and then try to do a design for our light fixture. And this company has done numerous designs for LED fixtures… thermal designs, I mean. So that's why that consultant was good and effective for that." (Couture, Interview, April 2, 2015). In a similar vein, ASC relied on technological consultants with expertise in sewing processes to help designing the sewing machine.

Analysis and conclusions

The more intense the collaboration, the more important strategic fit becomes. Developing radical EIs is a more uncertain process and requires more intensive interactions. Therefore, strategic fit is more important in radical EIs. This is reflected in the data, as strategic fit is only applicable in one incremental case, and seven radical EIs. The data also show that strategic fit is important not in sourcing new knowledge, but rather in efficiently applying it. For example, the case of ASC is interesting, as it proves radical EIs can still be successfully adopted when the (supplier) strategic fit is low. So it was effective, but not efficient, as it took four years to develop. In contrast, Kortec and Urthpact's supplier collaborations were characterized by high strategic fits and there were hardly any complaints about the adoption process.

For customer and competitor interactions, strategic fit is negligible. The customer is the one who pays, which ultimately is the lifeline of every profit-oriented organization, including manufacturers. Manufacturers are therefore customer-driven by definition. In one case (Urthpact), the customer was even more actively involved in the adoption of the EI, but this regarded a true joint development with back and forth prototype testing. Competitors are by definition strategically fitting. But because of the nature of competition, competitor collaboration does not occur naturally, and especially not in the process of developing innovations. Here, CP is the deviant case, because it is able to operate in a very friendly manner. Strategic fit with competitors would be necessary in the case of merges or acquisitions, or joint venture projects. Unfortunately, the sample did not comprise such a case.

For advisories, the situation is comparable to customers. Manufacturers are the customers of consultants, so the consultants need to make sure they adapt sufficiently to please the their demands. Whether or not there is a strategic fit does not really seem to affect the relationship, as it entails a formal business deal.

4.5 EI drivers and barriers

This paragraph will answer the double-parted research question D about EI barriers and drivers and the influence of regulatory actions in enhancing radical EI adoption. It is derived from the theory that EIs are generally more likely to be spurred by governmental interaction than their non-environmental counterparts (Pinget *et al.*, 2014). Here, we won't compare EIs with non-EIs, but instead focus on the difference between incremental and radical EIs. The qualitative data on the respective drivers for the different EIs are presented in a table in Appendix F. In the second column, the drivers are ranked on the basis of their relative importance, where driver number one is the most important driver.

The analysis is structured as follows. Firstly, an analysis of EI barriers is presented. Because the research only collected data from successfully adopted EIs, the data regarding barriers are not very rich and the analysis is thus kept short (Par. 4.5.1). More of a central focus of this paragraph are the drivers of the EI cases. Descriptives of the three clusters are presented in paragraph 4.5.2, which is followed by an analysis. Thirdly, paragraph 4.5.3 puts special emphasis on governmental actions as drivers of EI. This emphasis is legitimized as governmental actors are potentially important knowledge sources of manufacturing firms.

4.5.1 Analysis of EI barriers

This research has only analyzed cases of successful EI adoption. In order to write public policy recommendations, it is important to get a close understanding of the considerations that manufacturers make preceding an innovation project. Table 21 presents a list of barriers, or delimiting considerations that influenced manufacturers in their general and environmental innovation policies.

Perceived barriers of EIs		
Technological uncertainty	CP	"We have three presses of this size, we are quite reliant on this, if I had four or five presses I was able to go into this three years ago. But right now I have to be in production 18 hours a day, I don't have time to play." (LaValla, Interview, April 27, 2015).
Investment costs	DK, CP	"We make investments where we think we are going to make a gain in productivity or quality. [...] It has to balance out" (Wedge, Interview, May 5, 2015). "So if I was able to remove two pieces of them, which had less price value due to the less efficiency and put the new one in, it made the company stronger financially." (LaValla, Interview, April 27, 2015).
Lack of strategy	Fluorolite	Fluorolite's business model is so comfortable, that no innovation or growth is desired. Moreover, they don't do high-volume automated production.
Lack of governmental support	RemPhos	"The big thing in America is jobs and stop sending things offshore... I'm doing these things, but I've had no government support." (Gershaw, Interview, May 1, 2015).
Lack of customer demand	ILT	"Market information drives what product we're doing." (Couture, Interview, April 2, 2015).

Table 21: Perceived barriers of EIs

As the sample only comprised positive cases (i.e. successful innovations), there is not a lot of data to be analyzed regarding EI barriers. The data mostly agree with what the theory on EI and AC suggests. As said earlier, main barriers are financial (i.e. high investment costs, lack of customer demand), technological (i.e. high risk involved), and a lack of interest or strategy. We can also conclude that governmental (in)action can itself also be an important barrier to innovation. It was stated in the theory (Par. 2.1) that governmental actions drive the adoption of EIs. If we reverse this logic (i.e. a lack of governmental support is a barrier to innovation), we can see that RemPhos did not receive any governmental incentives to increase its staff, or to acquire more efficient production machinery. As a consequence, it did not adopt EIs in the US, but transferred its innovative manufacturing operations to China.

4.5.2 EI drivers

> *"So there was a financial decision, a production decision, and I'll say, a 'what's good for the environment' decision."*
>
> Joe LaValla (Colonial Printing) on the driving factors for acquiring the new HUV press (Interview, April 27, 2015). Notice the relative low priority of environmental drivers.

Descriptives incremental EI cluster

ILT is generally very much customer-driven. Customers would come to ILT with a certain challenge for a new product. The Canopy Light is not different, as in this case ESCOs came to ILT with specific product requirements. The government proved to be very effective, as ILT was influenced indirectly through rebates their customers receive for energy efficiency services. It is therefore important that ILT looks at the specific requirements for the rebates and does so in close collaboration with its electrical component suppliers. Regulatory actors communicate clearly through the web and communication is thus indirect. Additionally to energy efficiency regulations, there are also product requirements related to hygiene, which is communicated in a similar way.

Before acquiring the brazing furnace, LuxteL used to source this manufacturing process out to sub-contractors. Internalizing is first and foremost a financially driven decision. It increased LuxteL's manufacturing capabilities, which increases its sense of independency on the market and saves valuable time. Environmental benefits (e.g. less transport) are very much appreciated by LuxteL, although it was more of a side-effect. LuxteL was not influenced directly, nor indirectly by any governmental action in the decision to acquire the brazing furnace.

The adoption of low-flow faucets was primarily the result of market demand. Many retailers ask producers to be WaterSense certified. WaterSense is a certification scheme for water efficient products, rewarded by the federal-level regulatory Environmental Protection Agency (EPA). This label is rewarded to Symmons in case their faucets score below a certain flow rate. This is important for Symmons, because many competitors are doing the same, and because a large part of their market is in California, which is suffering a huge drought. This environmental hazard was a reason for the EPA to develop the WaterSense. The interaction is not very intensive: an agreement needs to be signed, after which the manufacturer has twelve months to obtain the certification. This is done by uploading draft designs and product specifications. There is no face-to-face communication and knowledge is codified.

Descriptives intermediate EI cluster

Draper Knitting bought the new dryer, because the two previous dryers were breaking down. It was to keep the manufacturing capabilities at a reasonable level. DK values the environment and does comply with any applicable environmental law. Nevertheless, "we haven't come far enough to make these things, you know, front and center as far as what we do." (Wedge, Interview, May 5, 2015).

For Colonial Printing, it was a similar situation, although the focus was more on relative cost reduction. When the new owner, Joe LaValla, took over three years ago he started thinking of possible efficiency improvements. He sold two presses of an older model and gained efficiencies in time and resources (i.e. less waste of ink, paper, electricity). Although the previous machines were not bad for the environment, the newer was even better, which was definitely included in the decision-making. Both DK and CP were abstained from governmental influence. In the case of CP, this is due to industry factors. There are no governmental incentives to develop EIs in the offset printing industry, as opposed to the wet printing industry, which has far more carbon emissions.

The case of Symmons' development of low-lead valves was only influenced by an amendment to the federal-level Safe Drinking Water Act, which included a further reduction of lead in plumbing products, including (shower) valves. This went in effect in January 2014, while it was only in October 2013 that Symmons decided to adopt low-lead materials in the production processes. The decision was made quickly, as time was running out. In case of non-compliance, Symmons simply would not be able to sell the valves, so it was a very serious affair.

Descriptives radical EI cluster

Kortec is very much customer-driven, but the Klear Can is more of a standard product. Customers did not jointly develop a product, but rather provided indirect demands. Environmental benefits are definitely valued, but were not driving the process. Governmental actions did not drive the decision either. However, as Kortec's core business is producing plastic packaging, it is constantly dealing with regulations around food safety or hygiene. The federal Food and Drug Administration (FDA) maintains a list of allowed materials. If your material is not on the list then you can apply to them with data. However, this was not necessary for the Klear Can.

LuxteL was influenced by a state-level regulation in the development of their mercury-free surgical lights. Manufacturers were required to report their mercury usages on a quarterly basis. This regulation lowered the aggravation of going completely mercury-free. It was an indication of the trend of environmental responsible behavior, which LuxteL already agreed with. So there was a direct influence that could potentially have accelerated the decision-making, although it could have done so without the regulation as well.

The main driver behind the automated sewing machine was a general strategy shift, which took place when Piasio investments acquired ASC in 2009. Since then, a growth strategy was applied, highly focused on lean manufacturing and data collection. However – indirectly, but relevantly - ASC was incentivized to develop the EI: "We actually got a 50,000 dollar grant from the state of Massachusetts to train, and the focus was on lean. And it just kind of snowballed. It was so effective that we decide to make it part of our corporate culture." From the grant, ASC hired a Director of Quality and he introduced the six sigma approach, which focuses on eliminating waste in the production process. In general, ASC is very much restricted by regulations. There are a lot of standards regarding hygiene, for example. ASC does not interact directly with governments, but hires regulatory consultants, as discussed in paragraph 4.4.

The main driver behind the coffee cartridges and valves was customer demand in the form of the SFBC company, who had a primary goal to offer more degradable products. After sensing market opportunities, IMS decided to spin off Urthpact, which has incorporated environmental concerns in its values. Urthpact was not incentivized and neither very much restricted by governmental actions. The only things they needed to be aware of were claims on packaging such as '100% compostable' or 'biodegradable'. There is strict governmental legislation on logo use and these kinds of marketing claims. Because biodegradability is still a new thing, there appear to be some institutional voids, because there is not yet one definition of compostability, for example.

Analysis

The different drivers of the EI cases are presented in Table 22, below. A distinction is made between direct and indirect drivers. Direct drivers are drivers that were crucial and sufficient conditions for the EIs to be developed, whereas indirect drivers played a secondary but helpful role.

Perceived drivers of EIs		
	Direct drivers	*Indirect drivers*
Customer demand	4x **ILT**, **SymmFaucet**, Kortec, Urthpact	-
Cost reduction	4x **LuxtFurnace**, *CP*, LuxtMercury free, ASC	-
Manufacturing capability	3x **LuxtFurnace**, *CP*, *DK*	-
Corporate sustainability	2x **LuxtMercury free**, Urthpact	2x **LuxtFurnace**, *CP*
Governmental regulation	3x **SymmFaucet**, **ILT**, Symmons valves*,	2x ASC, LuxtMercury free

Table 22: Perceived drivers of EIs.

Bold = incremental EI, underlined = radical EI, *italics = intermediate EI and '*'*=ambivalent case

A few things can be noted from the table. First, the influence of *customer demand* and *cost reduction* are most important in driving innovation. This is the case for eight cases, and is explained by the character of business: you have to be profitable to survive. This can be done by increasing your sales and listening carefully to customer demand, or also by increasing your company's efficiency and reduce costs. These two drivers seem to have no effect on the radicalness of innovation, as they are represented by cases from both clusters equally. When controlling for innovation type, one can see that customer-driven EIs are by no exception product innovations, because customers are the end users. This corresponds to the conclusion drawn in Paragraph 4.2.2. The third important driver is *manufacturing capability*, which refers to a necessary or desired state of a manufacturer's technical capabilities. DK needed to innovate because machinery broke down, whereas CP and LuxteL wanted to expand their capabilities. This driver is logical and a consequence of economic development, but does in no way correlate with EI radicalness. The fact that you invest in new machinery is to some extent radical as you 'depart from existing operations'. But how far this departure then is, does not depend on your necessity or desire for the machinery.

Corporate sustainability seems to be a direct driver of two EIs, both of which are radical. However, this is a coincidence, as corporate sustainability as a driver for EI has more to do with the company's values than the actual radicalness. For example, CP and LuxteL are less directly driven by corporate sustainability and accordingly have weaker values for sustainability in general. Urthpact markets itself as 'green' and this is part of its identity, whereas LuxteL does not prioritize sustainability, as its main business is about 'saving lives rather than trees'.

Comments regarding governmental interactions as drivers for EI and EI radicalness are presented separately in the subsequent paragraph.

4.5.3 Analysis of governmental interactions as drivers

The different forms in which regulatory sources influence innovations are push and pull factors. Regulators can push manufacturers *away* from undesired, polluting behavior or pull or drag them *toward* more sustainable behavior. Push factors exist in forms as prohibitive legislation (Symmons and the Safe Drinking Water Act), reporting (LuxteL's mercury use), and restrictions on food safety and health (Kortec, Urthpact and ILT). Pull factors consist in forms of grants (ASC), rebates (ILT) and certification schemes (Symmons' faucets). In assessing the relative influence, it is important to ask a counterfactual question: Would the specific EI adoption have occurred as well, in case the regulatory bodies did not act the way they have?

	Direct effect	Indirect effect
Push factors	Prohibition (Symmons valve*)	-
Pull factors	Rebates (**ILT**)	Grant (<u>ASC</u>)
	Certification (**Symmons faucet**)	Reporting (<u>LuxteL</u>)

Table 23: Governmental drivers of EI

Bold =incremental EI, <u>underlined</u> = <u>radical EI</u>, '*' = ambivalent *case*

The radical EIs were only *indirectly* influenced by governmental actions (ASC's grant, LuxteL's reporting obligation). For Kortec and Urthpact, the governmental influence was negligible as they comprised standard requirements regarding safety or logo use, which is located quite in the margin of the core business. The grant awarded to ASC was very successful, although it seems a lot of honor to consider the development of the sewing machine as a direct consequence. Rather, since the acquisition by Piasio Investments in 2009, the new innovation-oriented growth strategy would have led them to the EI anyways. This strategy expanded ASC's exploratory learning capacity as they were looking for alternative monetary resources, which eventually led them to the application for a grant.

For the intermediate EIs (both CP and DK), there was *no interaction* with regulatory bodies. It can be a coincidence that these two are concern process EIs, so it is important to check if innovation type does not relate with governmental interaction. However, the data do show that there is some correlation between the two (Table 23 shows four product EIs and just one process EI). In developing new products, there are always certain product requirements dealing with environment, health, or safety. On the contrary, there seem to be no specific regulatory requirements that interfere with the decision for the adoption of process EIs. Only for ASC it can be argued that a state-level grant relates indirectly to the development of the new piece of machinery. It can be hypothesized that these decisions are not affecting third parties (e.g. customers or patients) directly and therefore of less interest to the regulator. A counterargument would be that inefficient machinery has more negative environmental externalities, which does actually affect third parties (the general public) although in a less direct or observable manner.

The deviant case here is Symmons' 'just in time'-compliance with the Safe Drinking Water Act as it developed the low-lead valves. The very reason it scored incremental on market disruption is that it was the latest to the market with the compliance of the Act. Therefore, it would be more valid to consider this case as part of the incremental group rather than the intermediate group.

Of all incremental EIs, governmental interactions occurred *only* for product EIs (although it concerns just the single case of ILT). ILT's customers are influenced by rebates, which proves very effective. The energy efficiency requirements are very specific and thus guide the design process. Because ILT is customer-driven, these requirements are actually crucial for developing the Canopy Light. Less important are product requirements, which did not drive the Canopy Light, but rather made sure it was designed according the norms of (food) safety.

4.5.4 Conclusions EI barriers and drivers

The main barriers for EIs are financial (i.e. high investment costs, lack of customer demand), technological (i.e. high risk involved), and a lack of interest or strategy. It can also be concluded that governmental (in)action can itself also be an important barrier to innovation.

The most important *direct* drivers for manufacturers to adopt or develop EIs are financial reasons, being either efficiency improvements that lead to cost reductions, or developing new products as a result from listening to direct or indirect customer demands. Governmental interactions are also relevant in driving the development of EIs. For radical EIs, governments are less likely to exert direct influence. The data show no proof that they can do this, but are not strong enough to falsify the hypothesis.

For radical EIs, no governmental push factors can be observed. One could even question the possibility of push factors driving radical EIs, because a radical EI is explicitly 'early-to-market', whereas push factors are more likely to be ultimate measures and often have already been preceded by softer pull factors (e.g. subsidies, grants, rebates).

For incremental EIs, governmental actions are more effective. Incremental EIs can be directly caused by governmental action. It is likely that this is due to the nature of incremental innovation. Problems with the status quo, or desired future situations are within the realm of what governments can do. For radical EIs, there might be too many barriers preventing governmental interaction, such as powerful stakeholders' path dependency and vested interests.

Chapter 5. Discussion

After having presented general conclusions and recommendations in the previous chapter, this section reflects on relevant conceptual and methodological choices made in this research (Par. 5.1). It does so by showing the limitations and considerations of the theoretical backgrounds, the research methods and the results. Subsequently, paragraph 5.2 reflects on the contribution to the existing body of literature and presents three broad avenues for further research.

5.1 Research limitations

5.1.1. Conceptual considerations

Before going into a discussion on the quality of the methodology, it is first necessary to reflect on the research aim and the conceptual model. The aim of the research was to shed light into the differences of knowledge sourcing strategies that precede radical EIs, as well as to provide private and public policy recommendations to enhance the development of radical EIs. The aim is thus not to prove causal relations, but rather to see whether the concepts co-variate. Additionally, making policy recommendations implies that results should be generalizable to a larger population of manufacturers. It can be concluded that recommendations have definitely been provided, but the quality of these can be improved, which has to do with the choice of the model.

The conceptual model is a 'rejuvenated' model of relative absorptive capacity. This model incorporated many variables that play a role in interactive knowledge management. Additionally, all relevant knowledge sources were included, which has a multiplying effect on the data collection. As you can see in Table 6, there are seven factors related to the manufacturer's behavior or characteristics, four factors related to the EI, and six variables directly or indirectly related to the knowledge source. This research considers five different knowledge sources (although regulatory bodies were excluded in some parts of the analysis). This makes up for a large pool of variables, which increases the complexity of the research. A more narrow demarcation of the conceptual model or the knowledge sources would have benefited the validity of the results.

In a similar vein, also the conceptualization of the dependent variable, EI radicalness, is quite complex and this leads to a particular flaw. Due to the ambition to write both public and private policy recommendations, EI radicalness required to be defined with an inclusion of two domains: the internal, subjective firm-perspective and the external, objective market-perspective. By incorporating the two (or actually four if you look at both degree of uncertainty and disruption), the model better reflects reality. On the downside, however, it loses comparable value. The image becomes a bit too blurry. Consider for example Symmons' compliance with the Safe Drinking Water Act, which is internally a truely radical operation, whereas from the objective market-perspective, it is not radical at all. An alternative option would have been to define radicalness on either the internal or the external concepts. Obviously, this should be done in coherence with the research aim.

Another flaw in conceptual considerations is a case of circular reasoning in one of the independent variables. The definition of knowledge dependency already implies radicalness, as dependency was operationalized as disruptiveness. For example, if successful adoption of an EI is reliant on a large share of the employees, this means that more people need to be trained. I reasoned that the more training was provided, the more radical the EI was. However, the amount of training is actually a *consequence* of EI radicalness, rather than a constitutive element. This reduced the internal validity of this study, and could for example be resolved by excluding disruptiveness from the definition of EI and instead focus on the amount of uncertainty involved. Another way is to employ a clearer operationalization with a more narrow definition that emphasizes the differences between knowledge dependency and disruptiveness.

5.1.2 Methodological limitations

As presented in paragraph 3.4, there are different strategies to improve the overall trustworthiness of this research. The most important drawbacks of the methodology are data collection validity, use of alternative or mixed methods, and a negative case analysis.

Regarding the data collection, only manufacturers were interviewed, and only one per case. Validity was reduced by the fact that I make claims about innovation processes, but actually was not able to assess a process, but rather took a 'snapshot' of a situation. The interviewees were all part of the core group that decided on the EI, although in some instances the adoption process had taken place over ten years ago (LuxteL's surgical lights, and J&J). Due to Symmons' size and structure, its interviewee did not appear to be an optimal informant, as he was responsible for the manufacturing process and did not have detailed information about the design phase (in which external interactions occur more frequently). Looking at the qualitative nature of this study, it would have been more valid to also interviewed the external knowledge sources. The added value of interviewing knowledge sources would have been an increased overall validity as well as more specific insights in factors as trust, power, organizational fit and strategic fit. This would have resulted in more precise recommendations on how to engage in partnerships. It would have also corresponded better with the dyadic perspective that this research applied. Instead, to increase feasibility, the research opted to emphasize the manufacturers for different reasons (i.e. the research aim and the lack of prior research on organizational structure and innovation). However, originally, the model of relative AC is applied to analyze interactions more objectively, as it regards the two partners more equally.

Other flaws of the data collection would be the inexperience of the researcher. For starters, the acquisition phase took much longer than expected. The strategy of contacting existing and prospective clients of RenewThink did not work as its clientele does not consist of manufacturing companies, and neither did I, as a foreigner, have a personal network to benefit from. Additionally, engineering staff of manufacturing firms have very tight schedules, as they are constantly keeping an eye on operations. Regarding interview techniques, I regretted the fact that I was not more stringent and perseverant on getting the right answer. This is most true for the case of LuxteL. Some aspects of the acquisition phase were difficult to cope with. Firstly, the interviewees did not necessarily know beforehand which EI to talk about. I contacted them with a brief introduction and, especially in the US, you must drop a very short and convincing pitch to 'sell' your research. Manufacturers do not have much time. The fact that I could not offer much in return made me, in some instances, feel rushed. Secondly, I wanted to ask the manufacturer of every possible knowledge source and every possible variable, which has sometimes led to either superficial answers, or totally lacking answers. This reduced the study's internal validity and cross-case comparability. In the future, qualitative research with manufacturers should better prepare for a difficult interview acquisition phase, perhaps through personal contacts. Future research on the concept of relative AC should also critically consider to express a focus and narrow it down. For example, one could limit it to certain knowledge sources, or specific variables of the model.

Another limitation of this study is that it has only applied one research method: cross-case analysis. Method triangulation, or mixed methods, would have generated results that are more valid, both internally as well as externally. Quantitative methods could be opted for, looking at the many variables in the model. However, this would not fit the exploratory nature of the research objectives. Rather, a qualitative comparative analysis (QCA) would have added extra value. Applied to this research, a QCA would have enabled for an identification of combinations of KIs, or combinations of learning capacities that lead to radical EIs.

In general, a negative case is desired to "disconfirm the researcher's expectation and tentative explanation" (Burke Johnson, 1997, p.283). In this case, sampling negative cases is highly difficult, and maybe even impossible. My subjects of analysis are knowledge interactions. These interactions are implicitly directed at a goal: adopting an EI. Fluorolite could not function as a negative case, because there was no EI that followed any knowledge interactions. Negative cases in my study would have entailed EI projects that have been abandoned prematurely. Looking at the difficulty of the interview acquisition process, I have prioritized the actual successful innovators over the failed cases. Including negative cases in the sample would have been especially fruitful for the public policy recommendations.

5.1.3 Limitations of the results

In reflecting on the quality of the results, I would like to re-emphasize that the aim was not to explain correlations between variables and neither to show causality. Rather, it was aimed to see if certain knowledge management processes co-vary with radical EI processes, and others with incremental EI processes. Due to the comprehensiveness of the model, and the even more comprehensive reality, the results are quite meagre. The radar charts do show that KIs are significantly more intense for radical EIs. This is due to the fact that the more radical an innovation, the more uncertainty and risk involved in the process. These thus require more intensive KIs. Furthermore, the cross-case analysis asserts that supplier interaction is a necessary condition for radical EIs, while competitor interactions are unwanted when developing radical EIs.

In the analysis I have included some controlling variables that could also explain EI radicalness. Firm strategies seemed to be an important and necessary condition, for radical EIs to take place. ASC, Urthpact, and Kortec applied growth strategies with an explicit focus on innovation, whereas for example ILT did not. Innovation type was also influential, although it did not relate to the radicalness of the innovation, but rather determined the choice of knowledge source. Product EIs were adopted in close collaboration with customers, whereas for process EIs, the suppliers were more involved.

5.2 Research contributions and further research

This research aimed to fill three knowledge gaps, which it partly achieved. First, it was aimed to contribute to the knowledge on radical and incremental EIs. This research provided deeper insights into the differences, such as the different drivers and barriers. Also, general innovation processes were compared for both radical and incremental EIs. This relates to the second knowledge gap: that there is little information on how different knowledge sources affect or influence an innovation process. To fill that gap, both in-depth insights into the dyadic knowledge relations, as well as an externally generalizable representation of the reality were presented. A third gap that this research helped filling was the lack of empirical studies that apply the model of relative AC. Within the allocated time, it was challenging to apply the model, so a 'rejuvenated' model of relative AC was constructed and applied. Some difficulties that arose when using the model are decisions on which variables to include, and which to exclude. For example, *firm strategy* is very important in all the three learning phases. I have opted to include strategy in the conceptualization of exploitative learning, but additionally regarded it in the analysis as a contextual factor, while for the recommendations (see Chapter 7) it is regarded as a precondition. Moreover, what I have encountered is that the model is better suited to assess *intensive collaborations*, such as joint ventures or joint development projects. There is a difference between true intellectually challenging partnerships and mere transaction-based (knowledge) relations. For example, ad-hoc consultancy interactions did not provide very new insights by applying relative AC.

Three broad avenues for further research are identified, which I try to elucidate as specifically as possible, hereby helping to achieve the research aim to the extent this was not yet successfully done. The three avenues relate to the dependent variable, the theory, and the methodology.

If we reflect on the problem description, the main problem is the deteriorating climatic conditions. This was the starting point for this research. When funneling down from the corporate sustainability, to innovation management and knowledge interactions, I ended up constructing my own dependent variable: incremental and radical EI. For targeting the distant problem of climate change, it would be better to assess environmental impact of EIs.

In the process of writing the theoretical backgrounds, I decided to switch my focus from environmental impact to innovation radicalness, and regard the environmental impacts as a precondition for the innovation cases of my sample. The reason was that radicalness is more logically connected with knowledge management practices. And to include environmental impact – characterized by large uncertainty and variability - would only reduce the validity of the study and cause blurry results. Nevertheless, future research should implement environmental impact in the definition of EI.

Possible ways to do implement environmental impact in future research is by including the impact *intensity*, as applied in a quantitative study by Albino *et al.* (2012) or qualitatively by Carillo-Hermosilla *et al.* (2010). Horbach *et al.* (2012) included the *locus* of environmental impact, which also reduces the blurred image of EIs. While implementing the relative environmental impact is a way to increase the study's relevance, an opposing method would be to better demarcate EI and focus on a single EI instead of a diverse range of EIs. For example, a study by McAdam, Antony, Kumar, and Hazlett (2014) concerns the introduction of the Six Sigma program across multiple manufacturing SMEs. This facilitates for a more valid analysis, because the knowledge exchanged in the process is much more comparable. Future research should thus consider to narrow down to a single EI.

The second avenue for further research relates to the model of (relative) absorptive capacity. It has been argued that the theory of AC has been applied in research mostly in conceptual articles. This research added an empirical quality to the existing body of literature on AC. Nevertheless, more research is needed to make AC a more applicable concept. It appeared from this study that the concept is very broad and decisions should have been made regarding demarcation or narrowing down. Basically, any variable of the AC model can be an avenues for further research. For example, exploratory learning is in itself a process that requires more understanding. This research showed that different types of knowledge are sourced from different actors, but it does not, for example, provide insights in how to improve such exploratory activities. The application of the model could also be delineated to certain collaborative forms, such as alliances, or joint development projects.

The third avenue for future research concerns alternative methodological designs, compared to this exploratory study. Interesting follow-up studies could comprise a QCA, an institutional analysis, or a more in-depth case study based on data from all knowledge sources.

As this research was only exploratory, further research should take a next step and aim to establish causality. Causal relations are very difficult to establish between KIs and innovation outcomes, because there are so many different processes in between. Apart from mere quantitative methods, the QCA is a method that could help establishing causality. This is a middle-ground method in between qualitative and quantitative research (Rihoux, 2003). It is built on qualitative data, which are then quantified. It takes into account different variables simultaneously, and allows for the identification of 'causal recipes', or pathways for success (Schneider & Wagemann, 2010). This method enables the researcher to see if there are 'recipes' for success, i.e. combinations of interactions that lead to radical EIs.

Secondly, an in-depth institutional analysis could provide interesting insights into what governmental actions would work to enhance an overall adoption of radical EIs. This would also enable to direct more attention to the barriers of EI, a topic that this research did not elaborate on in much detail. Comparative institutional research should identify which public policies are more effective to break down innovation barriers. Such research would address the expressed need of Lane *et al.* (2006), who advocated for studies of institutional contexts and their effect on innovative firm behavior.

Thirdly, further research could take shape in a qualitative study, where data is collected from *all* parties of the innovating relationship, rather than just the manufacturers. This would provide more objective insights, as well as sketch different stakeholder interests, which should results in more socially legitimized public policy recommendations.

Chapter 6. Conclusions

This chapter provides answers to the research questions presented in Chapter 1. It will do so on a structural basis, and is followed by specific recommendations to enhance an overall increase of radical EI adoption. To remind the reader: the main research question was as follows.

How can knowledge management practices enhance the adoption of radical environmental innovations within small- and medium-sized manufacturers in the USA?

The main question will be answered by answering the sub-questions A – D, which is done below.

Sub-question A: How do external knowledge sourcing practices for radical environmental innovations differ from incremental environmental innovations?

This study investigated manufacturer's knowledge sourcing practices in the adoption of EIs with suppliers, customers, competitors, advisory organizations and governmental organizations. It can be concluded that overall, radical EIs require more frequent and more formal interactions than incremental EIs. This is due to the higher level of uncertainty involved in radical EIs. Knowledge interactions are not a necessary condition, as *any innovation - radical or incremental - can be developed purely internal.* It is important that the reader is aware that the sample is too small to make generalizable claims and will by no means enable the researcher to find necessary conditions.

Sub-question B: How do different external knowledge sources (suppliers, customers, competitors, advisories) play a role in the adoption of radical and incremental environmental innovations?

- Supplier interaction

Supplier interaction is necessary for any innovation. Where for incremental EIs supplier interaction is characterized by mere transactions and some design services, supplier interactions for radical EIs are truly equal, intellectually challenging collaborations, or joint development projects. Radical EIs require manufacturers to engage in structural or strategic partnerships (e.g. Urthpact, Kortec). Due to the newness of the innovation, it is often not necessarily beneficial to stick with current suppliers. For example, Kortec had a specific need and explored the world to finally find Kuraray, based in Japan. The same is true for Urthpact, who did not want to cooperate with suppliers that are very much path-dependent in old technologies (in casu: polypropylene). Urthpact proactively explored opportunities and found a more fitting supplier, although it was based in the Southern state of Georgia. In all instances except for LuxteL's brazing furnace, suppliers provided technological knowledge. In case of the radical EIs, technological knowledge also flowed from the manufacturers to the suppliers, while Kortec even passed on market knowledge to Kuraray as they needed to convince them of the Klear Can's market potential. In the *adoption* of process EIs, this entailed operational training on machinery (i.e. CP and DK), whereas in the *development* of EIs (both product and process) technological knowledge is more tacit and thus requires more frequent interaction. Notice the difference between development and adoption, which is directly relating to radicalness. Adoption is implementing something that already exists on the market (i.e. less radical), while development is creating something that did not exist before.

Regarding strategic fit, for radical EIs this is deemed more important. Radical EIs are more uncertain and require more interactions. Kortec also needed to convince Kuraray of the market potential, which indicates that radical EIs also involve a micro-level political game where persuasion and the creation of common identities and beliefs are important. Applying the same dominant logics definitely helps the efficiency of the adoption process. ASC for example, had a tough time developing the sewing machine, due to a lack of strategic fit with the automation company. Had ASC looked a bit further, one had perhaps found a better match and saved a couple of months or even years of development work.

- Customer interaction

The data show that customer interactions only occur in the case of product EIs. Process EIs are influential in the internal operations of the firm and are not affecting downstream consumers. Only ASC stated that the new sewing machine is an indirect effect of their strategy: being data- and customer-driven. Nevertheless, it is interpreted as a distant side-effect. An important conclusion is that customer interaction intensity is not of relevance for the radicalness. ILT (incremental) and Urthpact (radical) were the only ones that cooperated with customers in an equal joint development project. Similar falsifying conclusions can be drawn for both informal interactions at tradeshows (done by incremental ILT and radical Kortec), and formal customer feedbacks (by incremental Symmons' faucets and radical ASC).

Rather, customer interaction is dependent on innovation type and firm strategy. Does the manufacturer provide custom-made products, or does it employ a high volume production strategy? The former requires intensive customer collaboration, while the latter does not necessarily. The relationship between manufacturer and customer does not necessarily require a strategic fit. Customers mostly function as direct commissioners of new products, in which the relationship is more transaction-based and does not require intensive knowledge interactions.

- Competitor interaction

The main conclusion to be drawn regarding competitor interaction is that they provide very effective ways to learn for incremental EIs, provided that there is an atmosphere in which competitors are willing to share that knowledge. This was the case for CP, due to friendly personal relations of directors, as well as the fact that CP is not in full competition with the other printing firms. The more radical an EI, the less advantage one has from competitors interaction. Extremely radical EIs are by definition not preceded by competitor interaction, as the EI is new and unique. On the contrary, being a late adopter of an innovation (e.g. Symmons low-lead valves) makes it more fruitful to learn from competitors. CP has even done this purposively, as it waited for competitor's feedback on the HUV press.

Manufacturers share the best strategic fit with competitors. However, as EIs are developed with the aim of improving or maintaining competitive advantage, knowledge is not often shared. The only case in which this happened was CP, and strategic fit was identical, as the competitors had used the same machinery. CP could ask highly specific questions which proved very useful.

- Advisory interaction

Finally, interactions with advisory organizations such as consultants or research organizations only occur when there is an intellectual challenge (mostly technological, and rarely market knowledge) that cannot be solved by the manufacturer itself or by a close partner. Supplier partners could provide technological knowledge and customers market knowledge. Knowledge from external advisories is not necessarily affecting an EI's radicalness, but the data show that intellectual challenges are more likely to occur in radical EIs (i.e. Urthpact and ASC). In all cases of external advisory interaction, the influence is perceived to be effective and in one case (ASC) even crucial. Nevertheless, internal knowledge base (and the directly related firm size) is more determinant in seeking external help. This was the case for ILT that, due to a limited engineering staff, relies on outside technological consultants on a structural basis. The same is true for the concept of strategic fit, which is only beneficial in case of intensive collaborations.

Sub-question C: How do internal knowledge management practices relate to radicalness of environmental innovations?

Internal knowledge management practices are determined by a manufacturer's organizational structure and the extent to which knowledge is disseminated across the different departments of the organization. Knowledge dissemination capacity, or transformative learning, is only necessary when different members of the organization are affected by the EI. The more employees affected, the more dependent the EI is. EIs that score relatively low on dependency do thus not require a high transformative learning capacity. Therefore, the sample needed to be reduced, which negatively affects the generalizability of the here presented conclusion.

Of the reduced sample, all radical EIs (i.e. Kortec and Urthpact) were developed by manufacturers with a high transformative learning capacity. However, this does not confirm or reject any hypothesis, because there is a likelihood that a case exists where transformative learning is low and it still produces a radical EI.

Sub-question D: What are the perceived barriers and drivers of radical and incremental environmental innovations? And how can governmental influences encourage small- and medium-sized manufacturers to engage in radical EI adoption?

The most important observed barriers for EI correspond with what the theory claimed: economic, organizational, and technological barriers are important. A fourth barrier is governmental inaction, which led to innovation overseas (i.e. China instead of US, in the case of RemPhos).

According to the theory, EI drivers are market pull, technology push, and regulatory push and pull factors. The data confirm the theory, as the most important direct drivers were customer demand and technological development of the manufacturer (i.e. improving or maintaining manufacturing capabilities).

The *regulatory push* factor was directly relevant in the case of Symmons' compliance with the Safe Drinking Water Act. This push factor was very effective, because Symmons was extremely late in complying with the act. Regulatory push factors can also be effective more indirectly. An indirect push factor concerned LuxteL's reporting obligation of mercury use twelve years ago, which confirmed LuxteL's intrinsic feelings that mercury was bad and eased the decision to develop mercury-free lighting products.

Regulatory pull factors are important from a more distant, indirect perspective. For example, the grant that ASC received for implementing lean manufacturing and ILT's customers who receive rebates if they install efficient LED lighting. A third regulatory pull factor is a certification scheme, which in the case of Symmons is set up by the EPA. This label had a strong direct effect on customer demand as most retail companies now demand Symmons' products to be certified. Regarding radicalness, the data show that indirect regulatory interactions were more beneficial to radical EIs, whereas direct push and pull tools enhanced more incremental EIs.

Chapter 7. Recommendations

This chapter presents the recommendations to both manufacturers (Par. 7.1) and public policy makers (Par. 7.2).

7.1 Recommendations to manufacturers

First and foremost, it has to be made clear that knowledge sourcing is not a sufficient nor necessary condition for the successful adoption of radical EIs. And neither is there one pathway to success. The pathway to radical EIs is mostly dependent on the strategy of the firm. Take for instance Fluorolite, the company that fares well on a stable business model, and is run by a soon-to-be retired president. For Fluorolite, there is simply no incentive to innovate. A similar case is ASC, who employed the same stable strategy for numerous years, but, since it was taken over by another firm has started to thrive through a data-driven and innovation-oriented strategy. The recommendations that will be made are thus only of added value for manufacturers that employ a strategy that is already oriented at innovation.

Recommendation 1 – Expand exploratory activities

Knowledge is accessible everywhere, but recognizing knowledge as valuable is something different. In order to successfully develop or adopt a radical EI, a first step is improving the organization's *exploratory learning* capacity. This means opening up your organization externally and taking in information about the latest technologies, as well as from market demand. Examples are attending trade shows and conferences of industry associations. These events should be strategically selected. For example, RemPhos attends lighting conferences to monitor competitors and see the latest technology, but also conferences where potential customers would go to, such as energy efficiency conferences.

Recommendation 2 - Become data-driven and formulate specific goals

Employing an innovation-oriented strategy does not guarantee for successful adoption of EIs. What does help is being data-driven. Manufacturers are by definition already data-driven to some extent, but it does help to make everything measurable: resource inputs, product outputs, operational flaws, work hours, and time efficiencies. Having these data is valuable and enables for analysis and formulation of new goals. Without goals, there is no pathway to innovation. Operationally, becoming truly data-driven might be a challenge due to limited resources of SMEs. Overcoming this challenge is more effective for high-volume production manufacturers than for manufacturers operating in the low quantity, custom-made market, so there is always a cost-benefit trade-off to be considered. The federal program Manufacturing Extension Partnership (MEP) provides assistance in the form of technical or managerial training and there are state-level grants to help in funding the transition. A grant of 50,000 dollars is already enough to hire a Quality Engineer for one year. That is a lot of time to get flaws out of the production process and is likely to even save money for a permanent hire.

Recommendation 3 – Enhance internal cross-functional knowledge dissemination
Internal communication should be optimized, although not at all costs. Especially in smaller-sized manufacturers, organizing weekly cross-functional meetings helps to increase the connectedness of the organization. This benefits transformative learning, or the efficiency of EI adoption. Moreover, it increases exploratory learning, because there is more cross-pollination of ideas. For example, if a trade show was attended by two employees, let them report this to their colleagues. Additionally, it enhances employees' feelings of common identity and it builds ownership. A suggestion would be to combine this with the previous recommendation, thus sharing data across functional departments.

Recommendation 4 – Build trustworthy, new and strategically fitting relations

- 4a - Build *trustworthy* relations

All of the radical EIs under study were developed in close collaboration with external parties. Trust is a necessary condition for any successful partnership. Knowledge is a valuable resource especially for radical EIs, because they are aimed to create competitive advantage, which can be done by being first to market. Trust and secrecy in joint development projects are thus much appreciated assets. Practically, trust can be gained by asking other organizations for referrals, like ILT does. In case that is impossible, it can be built by collaborating in a small project first before agreeing on a long term deal, like Urthpact does.

- 4b - Build *new* relations

For radical EIs to be successfully developed, it is not necessarily good to continue doing business with existing, already trustworthy partners. Radical EIs rely on new knowledge, which is more likely to remain outside of the existing spectrum of partnerships. Before engaging in new relations, however, it is important to have either a well-articulated goal, or an articulated need. For example, ASC had a specific goal, and Urthpact had a need. Trust in new relations can be built by first engaging in a small project and continue if you are convinced of the partner's capabilities and trustworthiness.

- 4c - Build relations with *strategically fitting* partners

To enhance the efficiency of EI adoption, one needs to be sure of a certain level of strategic fit. Especially the development of radical EIs is a challenging iterative process that takes months or even years. Being on the same terms with your partner definitely benefits collaboration. Therefore, verify if the innovation partner has similar corporate values and has experience with the specific challenge. It is also useful if the partner has worked in similar contextual settings, such as industry or market. For example, Urthpact purposively collaborates with resin suppliers that have proactive environmental strategies.

Recommendation 5 – Keep an eye on competitors, but do not stare blind at them
Radical EIs are typically *not* preceded by close interactions with competitors. Competitor interaction should be limited to monitoring their websites and meeting at trade associations. In case you are only partly competing, informal direct interaction with competitors proves fruitful for the adoption of new machinery. For product EIs, there is not a lot of potential for competitor learning, as every manufacturer wants to maintain or improve its competitive advantage.

7.2 Recommendations to public policy-makers

After an analysis of the influence of governmental interactions in enhancing radical EIs, a few recommendations can be made. Unfortunately, due to the limited data on the evaluation of successful EI adoption and EI barriers, the recommendations are not as specific as desired. For public policy to enhance radical EIs, the technological aspects of EI radicalness are attenuated, as this depends highly on existing technologies and operations of the respective manufacturer. What public policy can do however, is to enhance the development of EI with an implicit focus on radicalness. Recommendations thus aim to improve an overall increase of EIs, but it depends on the manufacturer if this EI is incremental or radical.

Recommendation 1 – Facilitate knowledge sharing within the supply chain and between competitors

- *1a -Supply chain partners*

Supplier-manufacturer relations are by far the most important knowledge interactions in the development of EIs. Obviously, this is the market space, but it can be wise for the government to invest in supply chain collaborations. This can be done by funding knowledge sharing opportunities like trade shows and industry associations.

- *1b – Competitors*

Competitor interactions are especially fruitful for incremental EIs. Of all external interactions, competitor interaction is the most efficient, because the strategic fit is nearly identical between competitors: they face the same issues and have similar knowledge bases. Although competitor interactions do not occur naturally, barriers between competitor learning can be reduced by offering the right incentives. A possible policy could be to appoint leading environmentally innovative manufacturers as industry ambassadors. Ambassadors should teach other manufacturers about the multiple benefits of EIs. Manufacturers should desire to be an official industry ambassador, because of an increased marketing potential, respect from competitors, and a financial reward. This policy should be initiated by a governmental actor, but carried out by industry associations.

Recommendation 2 – Increase creativity in the manufacturing industries

Radical EIs require out-of-the-box thinking and often a creative linkage of technological possibilities and customer demands. Entrepreneurs are the creative actors that usually make those linkages. The employee base of manufacturers consists of technical engineers, (low-skilled) workers, and external sales or marketing people. In order to innovate, cross-pollination between engineers, workers and external employees should be enhanced. This could be done by providing organizational training on cross-functional interfaces. Another option could be to fund universities with multi- or transdiscplinar college degrees, or create new degrees, for example 'entrepreneurial engineering'.

Recommendation 3 – Increase funding opportunities for smaller-sized manufacturers

Economic barriers prove to be most influential. Smaller-sized manufacturers are less path-dependent than larger firms and provide therefore a better 'testing laboratories' for radical EIs. So the potential is there, but resources, especially monetary are often lacking. Radical EIs can be very costly to develop, and therefore government should provide the necessary funds to smaller-sized manufacturers. This can be done directly by providing grants to manufacturers to improve lean manufacturing or acquire more efficient machinery. An advantage of smaller-sized manufacturers is that a relatively small amount of money, could have more profound impacts than in large firms.

Recommendation 4 – Increase customer demands by providing rebates on environmental products

The fourth recommendation targets product EIs only. Customers should be incentivized to buy environmentally beneficial products. Due to the absence of ecoomies of scale, environmental products are generally more expensive. Look at the prices of LED lighting, or biodegradable plastic. This measure already works well in the cases of both ILT and RemPhos. Customers are incentivized by installation of products that require less energy.

Recommendation 5 – Increase prices of unsustainable practices and products

Costs are the most important barrier to innovation for SMEs. Assumingly due to their implicit uncertainty, EIs are more costly to develop compared to conventional alternatives. It is time to increase prices of non-sustainable products. Putting a price on carbon would spur he development of (radical) EIs. Manufacturers would have to pay more for their gas and electricity, and the price goes up annually. This makes the decision for manufacturers to invest in more efficient machinery easier. In a similar vein, taxation of non-degradable plastics would increase customer demand for degradable plastic resins. The Massachusetts state government is already actively exploring possibilities to do so and other states should follow this example.

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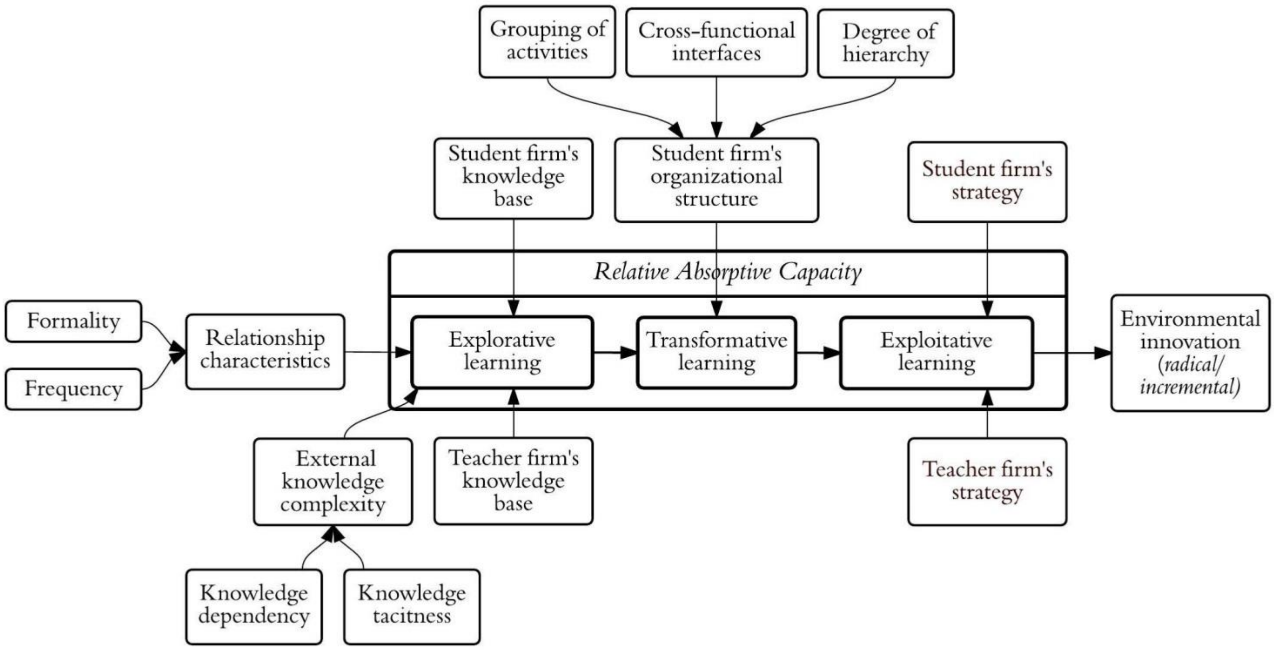
Appendix A – Conceptual model of relative absorptive capacity



Appendix B – Interview guide

Company and internal capabilities

- Core activities (incl. industry, customer segment, suppliers)?
- Organizational structure?
    - # Employees?
    - Hierarchy levels?
    - Functional managers?
    - Do managers have authority?
    - Employment:
        - In what areas do you employ people with academic backgrounds?
        - Do you need that in order to pursue strategies?
        - Cross-training?
- Idea of sustainability? Energy/material/toxicity/GHG/…?]
- Position in the market
- External trends (technological, or others)

Innovation and knowledge

- Describe the innovation
- New for society?
- New within the company?
- Description of the innovation adoption process, incl. decision-making?
- Was the innovation necessary?
    - Internal drivers (strategy? demand? technological development?)
    - External drivers (events, climate change, regulations?)

Knowledge interactions & knowledge sources ('checklist')

		Suppliers	Customers	Competitors	Gov't agencies	Research org/ consultants	Industry assoc./ Others
	Knowledge used?						
Knowledge source	Location						
	Knowledge base						
	Knowledge type (market/ technology)						
Knowledge interaction	Describe relation						
	Transfer-/ codifiability						
	Formality						
	Frequency						
	Trust						
	Strategic fit						
Evaluation	Problems						
	Perception of influence in adoption						
	Satisfaction						

Appendix C – Case summaries

Case A – ILT's Canopy LED Light

International Light Technologies (ILT) is an assemblage firm based in Peabody, MA. ILT employs around 35 people who are functionally divided over four product lines. Two of those are LED lighting for clients such as convenience stores and gas stations. Product innovations are driven by direct customer demands, after which they do a business case to decide if it stays in general product portfolio. The development of the Canopy Light took about eight months and was driven by Electrical Service Companies (ESCOs) who asked for a higher power energy efficient lamp. ESCOs are key customers because they deliver to numerous consumers and know the market. Governmental agencies, the utilities in this case, function as technical standard setting bodies. End consumers qualify for a rebates due to energy efficiency. Due to its operations in a niche, competitor interaction is minimal but they monitor competitor's behavior through the web. In the innovation process, consultants provide technical knowledge very frequently during the design phase. Specifically in this case a thermal engineer was hired, project-based. As an assemblage firm, ILT relies on electrical component distributors and their applications engineers. There is a close and formal interaction with suppliers, who offered design services as integral part of the sale of the components. However, the power supply manufacturer failed one of the preset requirements. The relationship with this manufacturer was new and distant (based in China), but they had a good third-party reputation. ILT didn't know 'how to communicate and how to really interact' and the manufacturer 'didn't know the questions to ask'. ILT admits it should have had more communication with the supplier's California-based office.

Figure 13: ILT's Canopy Light (www.intl-lighttech.com)

Case B - Colonial Printing's acquisition of the Hybrid UV Press

Colonial Printing (CP) delivers printing services, including commercial sheet printing and offset printing, to any organization 'that buys plenty', such as schools, colleges and retailers. Its main production facility and upper management office is located in Windsor, Connecticut and another production facility in Warwick, Rhode Island as well as a smaller shop in Newport, Rhode Island. CP employs around 110 people and has an executive committee (3 people from Windsor, 2 from Warwick, and 1 from Newport) that make decisions including buying the HUV press. The press is environmental beneficial an multiple ways: more energy efficient, time efficiencies (quicker runtime, less drying time), less ink use and no extra coating needed. The executive committee decided to look for a new press for driven by financial and professional concerns. The previous 2 presses were sold, because of their inefficiency but also because they were not exploited to the fullest. One press can meet demand. Competitors played a role in the acquisition process. CP speaks of 'our friends, the competitors'. They have been in the same industry for years and meet each other informally.

CP is ahead of the market but not a leader. CP has 'waited 3-4 years for the bumps to come out' and asked its competitors about their experience with the appliance. Komori, the manufacturer of the presses, provided a 6 week training as part of the acquisition. Another manufacturer, Heidelberg, also had good options but due to 'all of us had an allegiance to Komori' and 'we knew their equipment the best' Komori was chosen above Heidelberg. No consultants were hired for the press. Clients were not consulted either, because the product they buy hasn't changed in quality. Governmental agencies played no role in the process, because the printing market of CP has much less environmental concerns than for example the wet printing industry.

Figure 14: Komori's Hybrid UV press acquired by Colonial Printing. Model in image: Lithrone G40 (www.komori.com)

Case C - Kortec's development of the Klear Can

Kortec is a 'technology company that has some fundamental intellectual property around multi-layer co-injection technologies for plastics molding'. This technology enables the co-injection of 2 different polymers with complementing qualities into plastic products, in this case a plastic version of the classic tin can. So one provides the structure, so for instance polypropylene (PP), which is used in the Klear Can. A second polymer provides a barrier to oxygen prevents oxidization of the food inside the can.

Figure 15: Kortec's Klear Can (www.kortec.com)

Kortec employs 30 people of which over 20 are design engineers or processing engineers. Kortec is fundamentally customer driven: '[W]e were having (informal, red.) conversations at various trade shows and conferences with different customers and they are all saying basically the same thing: I want to replace metal cans with plastic cans'. For this radical new product a partnership with a plastic supplier was crucial. Kuraray, a Japanese company initially didn't want to partner because they thought the project impossible. Some convincing – Kortec did market research to opportunities of the plastic can and its potential revenues – was needed to get Kuraray on board. Kuraray had technical expertise on the what kind of plastic to use to guarantee a long shelve life. Milliken supplied additives but those were not crucial to the design, neither are other suppliers of plastics. Both relations were formal business relations. Interaction with Kuraray's production site in Texas was intensive in the design phase, but in the production phase it amounts up to once a month. Overall collaboration with Kuraray was very good, there was a good understanding of working towards a common goal. Also the Japanese culture tends to look at a longer term which suited Kortec's vision. They still meet face to face once a year to discuss, but actually 'the real agenda is to remain friends'. Kortec belongs to two plastics industry associations (SPI and RPPG) and visits conferences every quarter. This is used to monitor competitors and keep track of latest technological developments and to a lesser degree to talk with prospective customers. The governmental agency Food and Drug Administration (FDA) sets requirements around packaging for food, which put out on the web, but there was no direct communication with them in the case of the Klear Can.

Case D - RemPhos' remote phosphor technology

RemPhos is a manufacturer of LED lighting products founded by entrepreneur Dave Gershaw. He worked at multinationals Siemens and OSRAM Sylvania. At the latter company, Gershaw worked in an R&D team and developed the remote phosphor technology, which is yellow phosphor integrated in the plastic or glass lens of a lamp. Phosphor makes LED light white. This has to deal with wavelengths of light beams. Normally the phosphor is put directly on top of the diode, but in this case it is placed remotely above it. It has a higher efficiency, runs cooler, has a longer, more stable light and it is perfect for durable applications such as at airports and tunnels. RemPhos employs 'between the 100s of employees' of which 70% is in manufacturing. 10% engineering and 20% administrative positions. The main office is in Danvers, Massachusetts where also a bit of testing is done. Manufacturing is done in their China facility, as well as two other locations in the US. RemPhos is an informal spin-off of OSRAM Sylvania. Gershaw saw the opportunity and it was low risk because he already had a big customer from Sylvania. Competitors are gauged on lighting trade shows and conventions on an informal basis. For interaction with customers RemPhos attends clean building shows and conferences about energy efficiency. A third goal of trade shows are understanding the regulatory push-trends, to see 'where [electricity utilities'] policy is headed'. No formal interaction takes place with governmental agencies, but customers of RemPhos qualify for rebates which are usually granted by utilities (e.g. National Grid, NSTAR, MassSave), but those are 'private companies with a lot of public money'.

Case E – LuxteL's mercury-free surgical lights

LuxteL is a global supplier of xenon headlights for medical applications. It is a very small market with only one competitor in California and one in Japan. LuxteL is a very flat organization, employing five people, of which three are partly in production. In 2003, LuxteL decided to replace mercury from two special medical devices. A new, California-based supplier was found after some online research, but without any direct, trust-based linkage. The mercury-free products should have the same form, fit and function as its predecessors, so they presented the supplier the strict product requirements and asked if they could make that. Although the drive for innovation came from within LuxteL, the supplier had a proactive say in the development. It was a joint development process. At the time, the California and Vermont state governments started to set guidelines for mercury reporting, with other state governments following later. You had to report mercury usage every three months. This was a trend that made it easier for LuxteL to decide to go mercury-free. The basic drivers for the decision were financial as well as common sense about the environment. However, the general market trend was not showing any direction towards mercury-free products. 'The market was totally oblivious.' This also made it difficult to convince customers to buy the less harmful products. Competitors were not consulted because they were still making the old type of lighting. Consultants were not involved either.

Figure 16: LuxteL's mercury-free surgical optic headlight (www.luxtel.com)

F - LuxteL's brazing furnace

The furnace is to join pieces of metal, but in a controlled, vacuum environment to prevent oxidization. The furnace was bought second-hand three years ago and is about 20 years old. The decision was made by the five employees altogether. Reasons were financial, because now the brazing process can be done internally instead of contracting it out. It saves time and transportation costs and also enables LuxteL to carry less inventory. One of the employees looked on the web for a good furnace and then just picked one from a certain distributor. This colleague had worked with such a machine before and he managed to pull a manual together, and used some research of the furnace supplier to do so. The other two employees who are in the production department read the manual, but there was no formal training. Neither customers, nor suppliers had influence in this decision. No government incentives or restrictions. Competitors were monitored but no direct interaction.

Case G - Draper Knitting's drying machine
Draper Knitting (DK) is a sixth generation family-owned textile mill employing 40 people. DK makes roll fabrics that are used for a very wide array of products, including outerwear, paint roll covers, air filtration and heavy duty applications such as firemen clothing and racecar driver suits. Most of it is custom-made, so there is close customer collaboration in product development. But not for the dryer however, which was installed two years ago. The dryer gives the fabric a chemical treatment, coats it and dries it. The machine was bought brand new off a South Korean supplier and replaced two older machines from the 1940s and 1950s. Reasons for replacing were quality driven: DK needed more (technical) capabilities such as temperature and tension control and a larger width for the fabrics that run on it. The decision was made by 4-5 people of the product development team and the department manager and one person started orienting for new machinery based on a specific list of what they wanted. A few sales representatives came in and gave presentations. One colleague also went out and see the machinery running at mills where they were running the same machine. This was facilitated by the supplier and no direct interaction with competitors. In the US there are only one or two suppliers of the machinery, and DK wanted American made machines for marketing reasons. However, price was two or three times as high compared the South Korean machine. DK's production manager flew to South Korea and some representatives came to Massachusetts as well and a deal was signed. A Korean trainer stayed over for a couple of weeks. The learning curve was very long, around a year, which is quite normal for these types of machines. However, a minor imbalance of mutual expectations led to a deficient implementation, which didn't have crucial consequences. No technical consultants were involved, because it is such a small niche and neither any governmental regulations affected the acquisition of the frame.

Case H – American Surgical Company's sewing machine
American Surgical Company (ASC) is based in Salem, Massachusetts and manufactures neurosurgical patties, sold directly to hospitals in the US, while the international market is reached via distributors. ASC was taken over by Piasio Investments in October 2009. Since then, the company has been much more data driven and implemented the lean six sigma model. ASC employs 38 fulltime people and sometimes 10 part-timers depending on peak demands. Of employees 80% is in production. In the market, which is very small, ASC is 'the only company out there that aggressively develops and promotes neuro-surgical patties'. ASC now applies a growth strategy and has finalized a big reorganization last year. Part of this was implementing a fully automated sewing machine that replaces the previous predominantly (80%) manual labor intensive production process. This machine was custom-made over the course of four years in close collaboration with a company in Maine.

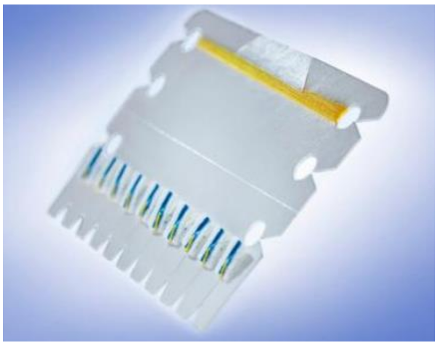


Figure 17: The 'Ray-Cot' neurosurgical patty, produced by automated sewing machine (www.americansurgical.com).

Because of its medical applications, ASC's products need to comply with regulatory requirements, which change constantly and differ per country. One employee functions as a liaison with some regulatory knowledge, but ASC relies heavily on external consultants for expertise in this field. However, this was not the case for the sewing machine. This radical new machine was developed mostly by the machine builder in Maine. This company was found based on informal trust relations but did not have experience with the industry and neither with sowing. Very close collaboration with ups and downs. Consultants were hired for programming and knowledge about sewing machines. Customers were not involved in this process, although customer feedbacks in general are taken very seriously and are quantified and evaluated structurally. Trade shows are attended for marketing purposes and networking with competitors and potential business partners.

Case I – Urthpact's biodegradable coffee cartridges and valves

Urthpact is a spin-off of Innovative Mold Solutions (IMS). IMS is a plastics company with injection molding technology as an expertise and has an engineering core. Within IMS a general market demand was sensed that directed them to work with biodegradable resins. The spin-off took place in January 2014 to better position itself in the market. Urthpact employs around 35 people, but some of the management roles and the engineering team are shared between IMS and Urthpact (together they employ 60 people). Due to its innovative nature, Urthpact has very little competitors in the US. In Europe there are companies doing the same thing but Urthpact is still focused on the US market. Massachusetts is the epicenter of the plastics industry with university facilities and big companies in the area. There is no direct, formal collaboration with competitors but due to geographic location Urthpact hires people from them, and vice versa. Informal and ad-hoc collaborations exist with Massachusetts universities University of Massachusetts in Lowell and the Worcester Polytechnic Institute which benefits technical challenges in product development. There is intensive iterative-based development interaction with suppliers of the plastic resins. In choosing suppliers, Urthpact typically collaborates on a small project first after which they quickly assess cost and benefits of a partnership. Size, financial stability and how deep their supply chain is, is important, as well as similarity to Urthpact regarding a high engineering percentage in the company and a focus on new technologies versus the existing. There is also intensive collaboration with customers, in product development (testing, prototyping, validation processes), starting with quite detailed product requirements. Typically, customers are very willing to collaborate and take their time to be able to dial in all kinds of modification. Government guidelines – constantly changing, hard to keep track of - restrict Urthpact in marketing claims such as compostability and biodegradability, set out by the FDA and the ASTM (American Society for Testing and Materials, red.) and is sent for approval by third party labs control this. No governmental incentives are provided.

Figure 18: Urthpact's biodegradable coffee cartridges(www.sanfranciscobaycoffee.com)

Case J – Symmons' manual low-flow faucets

Symmons is a manufacturer of plumbing products such as kitchen and lavatory faucets, and shower valves and heads. Symmons is established in 1939 and, with 300 employees, is one of the smaller players in the market. Typical customers are hospitality and residential buildings. In 2010, Symmons started to develop manual faucets with lower flow rates, which are more water efficient. The drought in California was one of the main drivers but also a general market trend was identified. For the faucets, a different flow restrictor was acquired through a supplier in Maine. The new restrictor required a different housing as well, but altogether that 'wasn't big of a deal'. The new flow restrictors were not new on the market. Competitors were already using the same types and Symmons' marketing team just went to buy some of those products to see how competition had done it (so no direct contact). Governmental requirements are set up in the context of the use of logos, such as the WaterSense logo (water efficiency requirements), but there are also requirements dealing with power of the water flow and the operation of the faucets. There is collaboration with domestic and international suppliers, which are always long term partnerships. They have regular meetings with bar stock suppliers to discuss pricing and strategies. No consultants were included in the process.

Figure 19: Symmons' manual low flow kitchen faucet. Model: Andora. (www.symmons.com)

Case K – Symmons' lead-free thermostatic valves

A more radical change within Symmons was the replacement of (low-)lead and brass materials to stainless steel for all the thermostatic valve products. The main driver were governmental regulations. 'If you didn't change it, you couldn't sell it.' It was quite a radical change because of the consequences for manufacturability. The year and a half process took place between 2012 and October 2013. Like in case J, Symmons 'can't go to [its] competitors and ask: Hey how do you run this thing?' The process was pretty much trial and error within Symmons engineering team. However, Symmons collaborated with tooling companies to help them with adjusting manufacturing processes for the stainless steel. This was a formal business relationship: Symmons buys equipment from the tooling company. As part of the deal, representatives would come in for 3-4 days to show how the machinery is operated and also helped Symmons' engineer to rig it and debug it (i.e. installation of the machine). While implementing the new processes, some minor mistakes were made but they were attributed due to time restrictions. Customers were involved from an operational standpoint, as they tested the prototypes and gave feedback through 5 of Symmons' sales representatives in New England. This happened in the summer of 2013 right before the launch. Symmons has attended two tradeshows (2013, 2015) to learn about improving the manufacturing processes in general.

Figure 20: Symmons' lead-free thermostatic valve. Model: Maxline. (www.symmons.com)

Case L – Fluorolite

Fluorolite is a company that manufactures custom-made plastic lenses or covers for lighting fixtures. It now employs 8 persons, of which 3 have a college degree and the rest works in low skilled production, like manual plastic molding or building wooden molds for the lenses. Fluorolite sits comfortably on a very fruitful business model. Normally, when a lamp's lens breaks down, one would buy a whole new fixture. Whereas Fluorolite offers a custom-made service, for just the lens. Fluorolite can ask a fee that is well above their investment but also well below the cost of a whole new fixture. Lenses are also applied to LED lighting, but the disadvantage of LED is that they have a longer lifetime, which reduces the possibility that the lens breaks down (which happens often during re-lamping). Customer interaction is limited to ordering. Customers would order a lens over the phone or through email or fax. Structural high volume customers are electrical distributors, who make up 75% of their market. There are not that many competitors who exploit the same business model. There's one in Florida, Georgia, and Minnesota. They are friendly and trade back and forth. Barriers to innovation are high investment costs. And moreover, because they do single volume production, there is no need to engage in efficiency innovations. Fluorolite also did not show ambition to grow in the future.

Case M - Johnson & Johnson

J&J is one of the global market leaders in medical device and pharmaceutical industries. It employs 128,000 people in 60 countries. The EI of concern is a company-wide change from packaging material to a less polluting plastic packaging. The innovation was adopted fifteen years ago, and the whole project took five years. Projects in the medical industry usually take long, because you're dealing with human lives, so testing and approvals are really important and might take months or years. Moreover, it was a massive operation due to J&J's size. The change was initiated by political and public pressure of environmental groups. A regulatory affairs group dealt with governmental interactions, which were plenty as each country has different rules regarding health and safety. Operationally it was a huge undertaking, very decentralized and in no way comparable to SMEs.

Appendix D – Qualitative data for EI radicalness

Case A – Canopy LED Light
"It's really not that radical per se. [...] The industry we are in is generally focused on replacing energy inefficient technologies with new LED more efficient technologies. So that's where we are focused on as a business. [...] [H]ow many employees would be affected by a change of the new power supply for example? [T]he purchasing person would have to buy from a different supplier. The marketing manager could care less, because the product is still doing what it's supposed to do." (Couture, Interview, April 2, 2015).

Case B – Hybrid UV press
"This press is about three years old, four years old. So when it first came out I waited for all the bumps and bruises to come out of it before I would jump in. [...] [T]his technology will be very common in the years to come, but today it's really not. It's just a handful of us throughout the country that have it. [...] Komori [...] sends in their trainers. And usually works with our staff for.. they were there for about 6 weeks. [...] Trained on it mechanically, had to replace rollers had to handle the ink, and this is a new technology. The problem solving with the papers and everything else." (LaValla, Interview, April 27, 2015).

Case C – Klear Can
"Obviously we had the co-injection technology, the machinery, the engineers who are familiar with the technology. So from that perspective it's just taking those things and making a small move. [...] Another way of looking at it is to say that what we did, and this is probably a truer way of looking at it, is to say, ok: here is a metal can, and our business has been replacing metal and glass with plastics, how would we then go about replacing this can? And ehm, whilst it's true that that knowledge base was there, that knowledge base was just one source of information and data to actually get creative about how you do that. So it is to say the real creative part was developing this base, and then the piece was done by Kuraray to actually develop a barrier material that would work for us. That is really where the creativity was coming from. [...] Today, nobody has a machine to make the can apart from us." (Bennett, Interview, April 27, 2015).

Case D – Remote Phosphor technology for LED lighting
"I was part of a team [at OSRAM Sylvania] that was writing IP, patents, on doing this new thing that no-one had done before. And because of my entrepreneurial spirit, I looked at it, and said: Oh, this is really cool, we're doing all this stuff in the lab, but the company I was working for needed somebody to actually make the products for them and it was a new process, required specialized equipment that they weren't able to find. I said: this is a cool opportunity to go start my own company and supply the company I was working for with this new technology. That's how I started the company back in 2008." (Gershaw, Interview, May 1, 2015).

Case E – Mercury-free surgical lighting
"[W]e had to totally redesign the product. We had to design something that had the same footprint and the same function as the old product. So it wasn't easy. [...] [T]he whole product [had to be removed], so we had to totally start again. A whole new product. It still has a nickel cadmium battery, which I prefer not to have, but it's better than mercury. Cause the mercury never goes. [...] [O]ur competitor still sells mercury version (after 12 years, red.)" (Interview, Beech, May 1, 2015).

Case F – Brazing furnace
"You said the furnace was a second hand and that it was not new to society (20 years old, red.), but it was new within your company? Yes that's right. Which is another way of renewing your practices. Too many people are buying new while it is not even necessary. [...] [W]ith research of the builder of the furnace [our lead person] managed to pull a manual together." (Beech, Interview, May 1, 2015).

Case G – Drying machine
"[W]hen we started the search [for the new frame], they (a Korean supplier, red.) came up and you know, after we evaluated everything, the technical expertise and we looked at the number of machines there were out in the field, which is one of the important things. We talked to people that are using their equipment now, and asked about how they responded if there was a problem. [..] There was somebody here for a couple of weeks, from the Korean machine building company. But, really, it took us a long time to learn how to run it. It was just different enough, and there were some issues with the machine in the beginning which weren't identified." (Wedge, Interview, May 5, 2015).

Case H – Sewing machine
"We had it designed just for us. It is innovation, it does not exist anywhere else. [...] As far as we know it's the only one in the world. [...] We're moving from what was primarily manual manufacturing production process, very labor intensive, about 80% of the process was manual labor to an all automated process. So the last 4 years we've been building equipment that will hopefully supplant all manual labor." (Piasio & Alouane, Interview, May 12, 2015).

Case I – Biodegradable plastic coffee cartridges and valves
"I would say considering the newness of the materials.. there is no..I mean polypropylene you can get a spec sheet and you could see all the characteristics of PP, but there is none of that (in the case of biodegradable resins, red.). We are the pioneers developing that. It requires high collaboration with the supplier and with the customer. [...] [T]his business (Urthpact, red.) is high volume high speed manufacturing in a earth friendly resin. It's very different than the products we are making in Innovative Mold Solutions. [...]. Our life science products tend to be very specialized, using plastics that are typically very resilient [...] In the defense space, the parts we make in defense are typically made to be indestructible, so they're not very interested in putting in the soil and that it breaks down.[...] So it's a very different model that, as we engaged with San Francisco Bay, Roger's Family company, we started to realize: Wow, it's an entirely different model." (Pousland, Interview, May 28, 2015).

Case J – Manual low-flow faucets
"Were any of those (manual low-flow, red.) faucets already on the market before you entered it? Yes.[...] All we had to do is change the flow restrictions in the faucets. [I]t wasn't big of a deal." (Kinney, Interview, May 29, 2015).

Case K – Lead-free valves
"Low lead material. That was radical.[...] A lot of our products are made from heavy metal. That's what Symmons was based on. [...] [S]witched over on some of our components to stainless steel, which was completely different direction, as far as manufacturability.. the speeds and feeds on our machines slowed down. We had to develop new types of tooling to improve tool life. Because you're wearing your tools, so the cost of your tooling is going up. So that was a big nag to swallow if you would say. So that was a completely different way of how to manufacture. [...] Do you think you were late in implementing this? I think we were a little late. We were probably the last ones." (Kinney, Interview, May 29, 2015).

Appendix E – Qualitative data for Transformative Learning

Please note that all citations derive from the interviews with the congruent manufacturer.

Incremental EIs

ILT	
Employees	35. "It's probably 70% that are skilled, either engineering, management, accounting, procurement, sales etc., as opposed to 30%, or 20 to 30% maybe, production and logistics."
Structure	4 product lines: specialty lamps, measurement equipment, general LED, and LED signage.
Hierarchy	"It's a pretty flat, it's a relatively small company. [...] We have our operations team, you know, production. Production is not organized per product line division, it's pretty shared across. [...] Some of the folks in operation tend to be more focused on one area than on another, but if they need resources, then they share resources across."
Cross-training	"*[Employees] are not very specialized in their functions?* Right, so our marketing manager does everything. And our two procurement guys tend to be a little more focused on one product line than another, but they do a little bit of both. [...] In this company. It's.. You know, you wear a lot of hats."
Other comments	"The engineers act as the design engineer, I have to act as the project manager who has to communicate with sales – who is also me inside the sales people – the marketing manager, the engineers and make sure everything comes together. So you know, it's a balancing act of who does what. And we help each other out."

LuxteL	
Employees	5. "[O]f which 3 persons are in production most of the time. [The other two] do sometimes. Everybody can, but 2 of us typically don't."
Structure	No clear structure. "We design, manufacture and sell here."
Hierarchy	"Admin work is divided equally." On the brazing furnace (case F): "We've collectively decided that we should do it, but my colleague found this particular machine online."
Cross-training	"Yes, everybody pretty knows how everything works and can replace one another. We don't have CFOs, no, bad news. I am the closest thing to a CFO. It's not a traditional company."
Other comments	LuxteL is such a small company that analysis of organizational structure is almost redundant.

Symmons	
Employees	300
Structure	There is sort of a functional division where specialized teams are responsible for different phases of product development (concept phase, business case analysis, design phase, manufacturing phase and product launch). Unfortunately, it is unclear how iterative this process is, and how much interdepartmental communication takes place.
Hierarchy	Quite hierarchical: "*OK. So this decision [to work with low lead materials] was made quite top-down?* Yes. And pretty fast. Should've been done earlier though. Should have been done when we moved from the 5 to the 6 series, instead of when we moved from 6 to the 7 series."
Cross-training	Little. Product development is really split into departments who have responsibilities in different phases: engineering team, product design team, manufacturing team, and quality department and then marketing launches the product. However there is a cross-functional mechanism in the form of a safety committee.
Other	Cross-functional interface in the form of a safety committee: "[I]t's a volunteer program. And

comments	they try to integrate it in the different departments. I am on the safety committee. Guy up in the screw machine department is on it. Preston over on purchasing is on it. [...] We have a new VP now, and he's spreading the word that we gotta be more safe and that makes sense. You got to be safe when you do your work. When people feel safe they will be productive."

Intermediate EIs

Draper Knitting	
Employees	40
Structure	DK is in the process of moving from "too many supervisory positions" to a more efficient, functional division, with separate fabric formation, product design, finishing/shipment, and sales departments.
Hierarchy	"And then we are in the process now, we happen in the last 5-6 years to reorganize the company. We had too many people. What happened at that point was.. we had too many supervisory positions. [...] [W]e want the supervisors to make their decisions in their departments. So, I guess... what is a good way to put it? We leave it up to people to set their limits what they can do. But once you make a decision, you own that decision." On the decision to acquire the dryer: "[I]t was the product development team and the production manager. And then we would always include the department manager or whoever was going to supervise that part. *So there's 5 people?* Yes, pretty much. So then we had discussions on new or used machinery. We started looking on what was used out there. Then we had a couple of companies come in and do a presentation on new machines."
Cross-training	"Everybody that works here, especially in management wears a bunch of different hats. Tomorrow I could be down beneath the drier looking at something. The next day I could be at some conference."
Other comments	"It is a family-owned company. 6 generations. The only people that have stock in the company are family members. So right now, Christine Draper is the president of the company, her father is vice-president."

Colonial Printing	
Employees	110 of which 65 in Windsor, and 35 in Warwick, where the HUV press was installed, and 10 in Newport. "[E]xcluding the office personnel, none of them have engineering backgrounds."
Structure	"We have 3 facilities overall as of today. The Windsor Connecticut, Warwick RI, and then we have a small shop in Newport RI." [...] "We have all upper management in here. So I work here, my CFO works here, our accounting department. Sales management is here too. And from there we are going into a full production environment. So we do print here, we have digital printing here [...], we do mail, we do photo, we pretty much do everything here, the same as the Warwick location does." Quite a functional division: sales team per location, but they do not have predefined territories, and there's production team in any of the locations and 1 production manager for the whole company. Quite centralized decision-making process: "executive committee, which is two people of the Warwick location, one from Newport, and then three at this location [Windsor] and includes myself. We pretty much make the decision, the direction we are going in, what's gonna end up where, what we are gonna lease, what we're not gonna lease, buy or not gonna buy." On decision-making: "So it kind of goes back to a decision which started about 3 years ago and that was the decision to acquire Colonial Printing. So I've only owned CP three and a half years now. The way that the company was staffed in the equipment was.. in personnel it had more equipment than it conceivably needed so what I was able to do is .. I sold 2 presses of an older model, not as efficient, different types of configuration. [...] So there was a financial decision, a production decision, and I'll say, you know, 'what's good for the environment' decision."
Hierarchy	Windsor and Warwick is more hierarchic than Newport, due to size: "[W]e have team leaders in each department here. And we have a plant manager in Warwick, who reports up to the

	production manager in Windsor. And then he has team leaders that fall underneath him and out in Newport they have 1 individual to which they all report, because it is such a small staff. And that individual reports up to me."
Cross-training	*"Cross-training?* We don't do that as much as we probably should do. Again, it's some of them are cross-trained, but not a lot of them. *So there's no structural cross-training?* No." "Marketing right now is between myself and the VP of Colonial. I'm on sales and he is on the executive so we do marketing together."
Other comments	There is quite a lot of communication across the locations, but not necessarily between the departments.

Radical EIs

Kortec	
Employees	30
Structure	Large skilled, technical core: "Yes we have sales, procurement, design engineering, process engineering, HR, that's basically it."[...] Approximately 70% are engineers. So they are either design engineers, who actually design the equipment. Or they are processing engineers who work with our customer to do the plastic processing to produce their containers. [...] And then the other 30% are finance people, and sales people like myself."
Hierarchy	*No data available.*
Cross-training	"Not really, pretty much of all of the development work we do now is driven by our customers. They come to us with a challenge. We apply our team, appropriately to try and resolve that challenge. [...] For any given challenge we will have a group of 2 or 3 people working as a team and that's how we kind of stimulate creativity. Here's the challenge, how would you approach that. Problem-based learning."
Other comments	-

ASC	
Employees	38 full time ASC employees, and about 10 temporary employees. About 80% of our people are in production. At the lower levels, it is primarily unskilled, although they have to have some kind of skill: dexterity, and paying attention to detail.
Structure	Low technological core.
Hierarchy	Quite hierarchical. There is a president, with below him a managing director receives reports from customer service, materials, shipping, quality control department, and manufacturing. The manufacturing has 3 supervisors and between 30-35 employees. There is also a VP sales & marketing who has 3 people under him. Finally, there is an engineer, who is a facilities and maintenance manager.
Cross-training	"That's one thing we are very keen on, cross-training, people wearing multiple hats. So.. just about everyone at the higher levels are cross-trained. For example, if our administrator out there is sick, or she's on vacation we have always two or three people who are able to back her up. There's always someone else."
Other comments	Lots of communication. Every week there is a data-meeting where all the numbers of the different departments are presented. ASC was acquired by Piasio Investments, a family's holding company in 2009 and since then applies a growth strategy with product diversification. Since August 2014 in the new building. Since 18 months an organizational change.

Urthpact	
Employees	40 employees. Around 25-30 in manufacturing and then 10 in office space roles or engineering leadership.

	Most of the people in manufacturing are trained on the job but without academic engineering degrees, although technicians are, and have over 30 years of experience. They are responsible for the process.
Structure	Urthpact is a spin-off of IMS (January 2014). IMS has been around since 1997 doing plastics manufacturing and injection molding in 3 key areas: Life sciences, Defense and Consumer applications. Around 7 years ago started to work with biodegradable resins. “We’ve always kept the engineering core intact. So the president of the company is a plastics engineer. And most of the leadership are engineers in plastics or some other technical way. So we’ve kept the engineering core, so that we are able to take on things like this [biodegradable plastics] that have a barrier of entry to market.”
Hierarchy	“[W]e’ve maintained that engineering-based organization to be able to [jump into new markets] [...] We are growing [...] but still relatively small agile organization. We are able to jump on things very quick. And bring the technology to market, like this [valve], quickly and flexible.“
Cross-training	“[T]his is a small company, I can say we are cross-trained to a high level. I come from a big company so it’s very different. In a small company when it’s August and lots of people tend to take vacation in August you are wearing all kinds of different hats. And I would say the longevity of our employee base is very good where cross-training is definitely happening.” For example, the employees have all been part of the company since a relatively long time, even the manufacturing staff. “I would say we’re probably high on the scale of cross-training just because of that. As we grow bigger, and we are seeing this kind of explosive growth, that’s one of the things where we’d say: how do we maintain that? How do we maintain our agility, to be able to jump on these new things, as well as you know, keep a staff that is more broad-based versus a silo kind of organization. We don’t want that.”
Other comments	“One of our company’s values is collaborative innovation. That is a value of ours, that we don’t accept people who are saying: that is not my job. And trust me, haha, I’ve been places, at companies where people say that’s not my job, that’s his job. We all have the same mission.”

Appendix F – Qualitative data for EI drivers

Please note that all citations derive from the interviews with the congruent manufacturer.

Incremental EIs		
Cases	**Drivers**	**Data**
A **ILT**	1. Direct customer demand 2. Indirect state-level rebates	"The reason that we developed that unit (Canopy Light) was: we had a number of third parties (the ESCOs) asking us for a higher power, a certain configuration, so they fed us back more detailed information of what that product needs to look like." ESCOs are in direct touch with end-users of the lights and receive rebates from Massachusetts state government on every sold piece of efficient lighting, provided that they comply with specific product requirements.
F **LuxteL** **(furnace)**	1. Financial reasons 2. Manufacturing capability 3. Environmental concerns	The acquisition of the brazing furnace internalized one manufacturing process, where previously "we used to send all of that operation to other people to do. By bringing it in house I save on freight transport. Burn less gas. I save a lot of time. I carry less inventory. All sorts of benefits. Time benefits too." But most importantly "it is more economic on site, rather than sending it all over."
J **Symmons** **(faucets)**	1. Customer demand 2. EPA certification 3. Environmental hazard	Symmons was triggered by three interrelated reasons. The California drought is a big driver, which leads to an increased market demand for water efficient faucets, especially in California. This spilled over to a national level where the Environmental Protection Agency (EPA) started a certification scheme called WaterSense. "And in order to play in the retail market place, you need to be WaterSense certified."

Intermediate EIs		
Cases	**Drivers**	**Data**
B **Colonial Printing**	1. Cost reduction 2. Manufacturing capability 3. Environmental benefits	When the new owner, Joe LaValla took over three years ago he started thinking of possible efficiency improvements. "I sold two presses of an older model [...] Although they weren't bad for the environment, they didn't have the efficiencies of the low energy, the lower paper waste." The HUV press replaced the two other presses and this saved them investment capital, operational costs due to efficiency gains in resources as well as in time.
G **Draper Knitting**	1. Manufacturing capability	"We make investments where we think we are going to make a gain in productivity or quality.[...] we bought a new dryer, because we had to. The others were breaking down, it was a quality thing. It was not to save resources." Nevertheless, sustainability is of concern of DK, but not a high priority: "even though that we hold these things important as far as environment and sustainability, you know, in my mind we haven't come far enough to make these things, you know, front and center as far as what we do." DK is very careful and does comply with environmental regulations, but does not incorporate it into innovative behavior.
K **Symmons** **(low lead valves)**	1. Federal-level regulation	The federal government came with an amendment to the Safe Drinking Water Act, which included a further reduction of lead in plumbing products, including (shower) valves. Symmons found out in October 2013, where the amendment would be in effect in January 2014. There were no other drivers than that: "If you don't do it, you don't sell it. And the first places that we had to be compliant were Louisiana, California and Vermont. And now the Federal Act is already done. It's countrywide now."

Radical EIs		
Cases	Drivers	Data
C **Kortec**	1. Customer demand	Normally Kortec is very much customer-driven, but the Klear Can is more of a standard product: "We were having conversations at various trade shows and conference with different customers and they are all saying basically the same thing: I want to replace metal cans with plastic cans. But no one came to us and said: let's do that, you know, as a project. Instead of working with a customer on the Klear Can we have actually developed this ourselves." Environmental benefits are definitely valued, but were not driving the process.
E **LuxteL (mercury free)**	1. Financial reasons 2. Environmental concerns 3. State regulation	Mercury was expensive, so sourcing other raw materials was primarily a financial driver. But regulations aggravated the decision-making: "The state of California and Vermont began to sign legislation that is more restricting. [...] We had to report our amounts of usage. Every quarter. So there was other incentives." For LuxteL sustainability is not a first thing as it focus is on the patients' health, but "everything we do, we try to reduce our footprint. We sort our trash. Paper, plastics, etc. We recycle all our metals." LuxteL on corporate sustainability: "We are aware that those things are desirable, but we just don't think it's necessary to put it into music. If somebody buys from me because we do that, then that's the wrong reason to buy it from me. Everybody should do that."
H **ASC**	1. Growth strategy 2. Indirect by state grants	Since 2009 ASC employs a growth strategy and is highly data-driven. Piasio: "The previous owner was not growth oriented. Its revenues base were basically flat. He was making a healthy profit and he was happy with it. The new ownership is growth-oriented. We've doubled the revenue in the last five years. And we're hoping to continue that process.[...] "We actually got a 50,000 dollar grant from the state of Massachusetts to train, and the focus was on lean manufacturing. And it just kind of snowballed. It was so effective that we decide to make it part of our corporate culture."
I **Urthpact**	1. Customer demand 2. Environmental concerns	As the market demand for degradable plastics started to burst, IMS spun-off Urthpact. The coffee pods and valves were developed from direct customer demand: "We get a call from a company [San Francisco Bay Coffee] that wanted to make a biodegradable single serve coffee package. Their primary goal was to get something on the market that was biodegradable."