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Integrating knowledge for environmental innovations in research centres: the key role of industry-based boundary spanners

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Abstract: Although the specialised knowledge of universities is considered a significant contribution to firms' environmental innovations, gaps remain regarding how firms integrate this knowledge. A rising literature stream on boundary spanning and knowledge integration seeks to investigate how firms achieve such integration; however, in-depth studies at the individual level are lacking. To develop this understanding, we conducted a longitudinal study of industry-based boundary spanners and their knowledge integration activities in research centres. We identified a set of underpinning knowledge transferring, translating, and transforming activities that are performed internally in firms and externally towards research centres to create environmental innovations. We also revealed a pattern in how boundary spanners attend to these activities in the establishment, performance, and end stages of research centres, thus providing guidance for theory and practice on how to develop environmental innovations in research centres.

Keywords: inter-organisational collaboration; open innovation; university-industry collaboration; research centre; environmental innovation; boundary spanning; boundary spanner; knowledge management; knowledge integration; knowledge transferring; knowledge translating; knowledge transforming; Norway.

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1 Introduction

External knowledge is a key driver of firm innovation in general (Grant, 1996a; Chesbrough, 2003; Tell, 2011), and for environmental innovations in particular (De Marchi, 2012; Cainelli et al., 2015). Universities are an external knowledge source that often provides specialised and complementary knowledge to firms' through university–industry collaboration (Cohen et al., 2002; Plewa et al., 2013; Galán-Muros and Plewa, 2016). A predominant policy initiative to facilitate the integration of this knowledge into firms' environmental innovations is to establish research centres in which university and industry partners collaborate (Geisler, 2003; Ponomariov and Boardman, 2010; Jakobsen et al., 2019). Such research centres often seek to overcome specific challenges in particular industries (Gulbrandsen et al., 2015) or tackle some of the 'grand challenges' facing humanity, such as the climate crisis (Hessels et al., 2014). Prior literature has shown that successful outcomes, such as innovations, patents, and licences, can be generated through these collaborations (e.g., Mansfield, 1991; Cohen et al., 2002; Ponomariov and Boardman, 2010). These studies are typically based on panel data (e.g., Kobarg et al., 2018; Robin and Schubert, 2013), large-scale surveys (e.g., Cohen et al., 2002; De Marchi, 2012), or archival patent data (e.g., Kaiser and Kuhn, 2012; Soh and Subramanian, 2014), thus demonstrating that university partners' knowledge has been integrated into firms' environmental innovations.

However, less is known about *how* these outcomes are achieved (Johnson and Johnston, 2004; Perkmann and Walsh, 2007; Lauvås and Steinmo, 2019). Many firms face significant institutional and knowledge barriers during collaborations with universities (Bjerregaard, 2010; Steinmo, 2015) and struggle to integrate their specialised knowledge and research findings (Harryson et al., 2007; Galán-Muros and Plewa, 2016; Miller et al., 2016), posing an important research gap that needs to be addressed. An emerging body of literature indicates that knowledge integration, which focuses on firms' ability to integrate specialised but complementary knowledge (Tell, 2011), may elucidate how firms can benefit from and integrate external knowledge (Perkmann, 2017; Zahra et al., 2020). However, the literature on university–industry collaborations often focuses on knowledge integration *outcomes* but lacks evidence of the knowledge integration activities that lead up to these outcomes (Tell, 2011; Perkmann, 2017; Zahra et al., 2020).

This study addresses these shortcomings by exploring the knowledge integration activities performed by key individuals involved as industry partners to act as a link between firms and universities (Santoro and Chakrabarti, 2002; Knudsen et al., 2017; de Wit-de Vries et al., 2019). To delve into the dynamics of the knowledge integration activities performed by these key individuals, we also draw on the interrelated theoretical concept of boundary spanning, which focuses on the specific individuals (i.e., boundary spanners) who mediate between the external task environment and the focal firm (Birkinshaw et al., 2017; Tushman and Katz, 1980). In our case, we explored how industry-based boundary spanners perform knowledge integration activities between their

firms and university partners over time, posing the following research question: *What knowledge integration activities do industry-based boundary spanners carry out across different stages of a research centre?*

Given that the literature on knowledge integration and boundary spanning has mostly remained separate, we address our research questions using an abductive-analysis approach based on a longitudinal multiple-case study of industry-based boundary spanners involved in six 'Centres for Environment-Friendly Energy Research'. These research centres are financed by the Research Council of Norway and provide a unique setting for studying knowledge integration activities, as the centres involve long-term collaborations between universities and firms aiming to generate knowledge relevant to environmental innovations.

This theory building paper contributes an in-depth understanding of the underlying dynamics of university–industry collaborations working towards innovation in general (Perkmann and Walsh, 2007; Galán-Muros and Plewa, 2016), and environmental innovations in particular (Yarahmadi and Higgins, 2012; De Marchi, 2012; Hermundsdottir and Aspelund, 2021) and offers two main contributions. First, we identify the underpinning activities of knowledge transferring, translating, and transforming that are performed internally in firms and externally towards research centres (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017), which contribute insights on *how* firms should be involved in these collaborations to realise outcomes, such as innovations (Harryson et al., 2007; de Wit-de Vries et al., 2019). Second, our study reveals a pattern in how boundary spanners attend to these key activities in the knowledge integration process (Carlile, 2004; Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017; Hayter et al., 2020) that unfolds during the establishment, performance, and end stages of a research centre (Skute et al., 2019; Zahra et al., 2020). As such, we provide insights into the absorptive processes leading up to innovation (Song et al., 2018).

This paper is structured as follows. The next section reviews the literature on boundary spanning and knowledge integration related to the context of university–industry collaborations. Section 3 presents the methodology used, and our empirical findings are presented in Section 4 before they are discussed in relation to the scholarly literature in Section 5. Finally, Section 6 highlights the conclusions and implications of our findings.

2 Boundary spanning and knowledge integration for environmental innovations in university–industry collaborations

To delve into the setting of environmental innovation development in university–industry collaboration, we draw on the interrelated theoretical concepts of boundary spanning and knowledge integration in the context of university–industry collaborations.

2.1 Research context: university–industry collaboration

Although university–industry collaborations may generate successful outcomes, they are often challenging because they consist of heterogeneous partners with distinct knowledge bases (Perkmann, 2017; Miller et al., 2016). This is one explanation for why university–industry collaborations are found to be highly rewarding but also utterly challenging

(Hounshell and Smith, 1988; Steinmo, 2015; Estrada et al., 2016) – that is, partners most likely to provide complementary knowledge are generally also the most challenging actors to collaborate with (Ratcheva, 2009; Howells et al., 2012). Hence, university–industry collaborations are challenging because of the inherent knowledge boundaries, with universities holding and nurturing disciplinary and generic knowledge and firms having more product- and technology-specific knowledge (Brocke and Lippe, 2015; Perkmann, 2017).

The successful bridging of university and industry partners' knowledge boundaries is further demanding due to their different cultures, motivations, and contradictions in incentive structures and the opposing logics and goals between academic publications and industrial commercialisation (Perkmann and Walsh, 2007; Steinmo, 2015). Accordingly, the partners often have different time horizons, where universities are more long-term oriented and firms more short-term oriented towards results that can solve short term-problems (Hounshell and Smith, 1988; Bjerregaard, 2010; Steinmo, 2015).

Recent findings have illustrated that social integration mechanisms through the concepts of social capital (Steinmo and Rasmussen, 2018), proximity and mutual commitment (Lauvås and Steinmo, 2019), institutional logics (Bjerregaard, 2010), governance void (Jarvenpaa and Valikangas, 2016), and coordination mechanisms (Isaeva et al., 2021) can contribute to a better collaboration process between the partners, thus leading to more successful outcomes (Mathisen and Jørgensen, 2021; Bjerregaard, 2010; Jarvenpaa and Valikangas, 2016; Isaeva et al., 2021). However, there remains a lack of insight into how firms actually integrate the knowledge from these collaborations (Harryson et al., 2007; Galán-Muros and Plewa, 2016). Studies on boundary spanning and knowledge integration may provide insights into these aspects.

2.2 Boundary spanning

The concept of boundary spanning is well established and has been deemed foundational for understanding how organisations access information and knowledge from their environments through specialised individuals or units (Tushman and Katz, 1980; Birkinshaw et al., 2017). This study operationalises boundary spanning at the *activity* level, thus focusing on the individuals who span boundaries – namely, the boundary spanners. Boundary spanners are individuals who function as the 'link between a unit and its environment' (Haas, 2015, p.1034), facilitating and managing the inflow and outflow of knowledge between organisations (Tushman, 1977; Tushman and Scanlan, 1981). Hence, boundary spanners have a twofold function: to maintain contact with the external environment and gather information and knowledge from it, and to maintain close contact with the internal organisation to integrate the information and knowledge in a way that is understandable to their colleagues (Allen et al., 1979).

In the context of research centres, the function of boundary spanners thus implies being firms' link to university partners. Several studies have found that firms are critically dependent on their boundary spanner work with research centres (e.g., Knudsen et al., 2017; Takanashi and Lee, 2018). This general finding was evidenced by Santoro and Chakrabarti (2002), who found that only five out of 202 firms participating in US research centres involved more than one boundary spanner working with research centres. This finding illustrates the importance of a single boundary spanner's skills and activities if a firm is to integrate the specialised knowledge of its university partners.

Although boundary spanning has existed for many years (e.g., Tushman and Katz, 1980) and is intuitively a key process in generating knowledge outcomes and environmental innovations in university–industry collaborations, we know less about how it is carried out. Most prior studies have taken a general view of boundary-spanning activities and concluded that boundary spanners should be committed and involved in university–industry collaborations for firms to benefit from them (e.g., Santoro, 2000; Mora-Valentin et al., 2004; Núñez-Sánchez et al., 2012).

However, some scholars have recently begun to provide insights into how this commitment and involvement should be put into action by studying the types of activities that boundary spanners undertake to integrate knowledge into interorganisational collaborations in general (Birkinshaw et al., 2017; Monteiro and Birkinshaw, 2017) and from universities in particular (Takanashi and Lee, 2018). Accordingly, drawing from a qualitative case study of Irish research centres, Ryan et al. (2018) asserted that attitudinal behavioural modifications by firms' boundary spanners enhance firms' innovation capabilities over time. Similarly, based on a survey of firms' boundary spanners in university–industry collaborations, Takanashi and Lee (2018) found that boundary spanners who ensured effective communication and trust with university partners helped align different interests, which in turn had a significant effect on project performance and knowledge development in their firms. A survey of highly involved university–industry collaboration partners by Hamadi et al. (2018) contributed insights into the boundary-spanning characteristics that are important at different stages of collaborations, showing that spanners should build internal support and good relations with university partners in the initiation stage and should engage their expert knowhow, communicate, coordinate, and supervise in the performance and termination stages.

These findings have generated insights into the value of boundary spanning but remain somewhat abstract, providing limited guidance on how this value could be realised. Given that boundary spanning is challenging (Bechky, 2003; Kaplan et al., 2017), several scholars have called for in-depth investigations of how boundary spanners actually span boundaries in interorganisational collaborations in general (e.g., Halevy et al., 2008; Tell et al., 2017; Langley et al., 2019) and how they manage to integrate knowledge from university partners in particular (Perkmann and Walsh, 2007; Harryson et al., 2007; Hayter et al., 2020), which we discuss in more detail below.

2.3 Knowledge integration

Knowledge integration focuses on 'combining specialised but complementary knowledge' (Tell, 2011, p.27) with the purpose of taking advantage of actors' differentiated knowledge bases and complementarities (Enberg, 2007). Knowledge integration is closely related to firms' ability to "recognise the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p.128), whereby the role of prior knowledge in the absorption of new knowledge is well studied and accepted. However, it has been found to have a limited effect on firm outcomes regarding knowledge, innovation, and performance, whereas firms' *absorptive processes* have the highest effect on firm outcomes although they have received limited attention (Song et al., 2018).

Hence, this study investigated the theoretical foundation of absorptive processes, namely knowledge integration processes (Song et al., 2018), performed by industry-based boundary spanners. A range of separate theories on knowledge transfer and integration

(Grant, 2017) have been developed, with several contributions from frameworks and conceptual models (e.g., De Boer et al., 1999; Grant, 1996b; Ratcheva, 2009; Carlile and Rebentisch, 2003; Mohannak, 2013; Miller et al., 2016). However, few empirical studies have been grounded in these theoretical frameworks and constructs,[1] resulting in conceptual ambiguity regarding the concept of knowledge integration, which has impeded the development of a coherent stream of knowledge. Perhaps the neglect of knowledge integration activities has occurred because both the knowledge integration literature and the knowledge transfer literature (Miller et al., 2016) lack a fine-grained theoretical framework for studying and understanding the processual aspects of collaborations at the micro level (Foss et al., 2010).

To address this void, scholars have recently advocated employing three dimensions – knowledge transferring, translating, and transforming (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017; Hayter et al., 2020) – which have been applied in the literature on knowledge sharing and integration (Kellogg et al., 2006). Most scholars have contributed to these dimensions either by focusing on one dimension separately or by integrating two of them (e.g., Adler, 1995;p Pawlowski and Robey, 2004; Bechky, 2003), whereas Carlile (2004) integrated all three dimensions into a single framework for understanding the processual aspects of knowledge integration.

Although Carlile (2004) focused particularly on the complexity of communication for product development within a single firm, the framework is suitable for a wider array of collaborative activities. However, Carlile's (2004) framework also has some shortcomings regarding empirical validation and the particular knowledge integration activities that underpin the three dimensions, which Le Dain and Merminod (2014, p.690) commented on as follows:

> "Carlile… does not offer any empirical validation… The framework was primarily defined… without clearly specif[ing] what are the current activities encountered in a new product development project related to each dimension of knowledge sharing (transfer, translation, transformation)."

Hence, although the three dimensions have received criticism for limited empirical validation, thus remaining as useful conceptual distinctions (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017; Hayter et al., 2020), the next section aims to briefly illustrate the practical possibilities of Carlile's (2004) framework by connecting the three dimensions with the empirical literature on university–industry collaborations. Still, it is important to point out that the logic behind the dimensions is complex, so interested readers should refer to Carlile's (2004) original work for a complete account. In the next section, we explain the essence of the dimensions and account for our operationalisations of the dimensions in the context of our study.

2.4 Knowledge transferring, translating, and transforming

Knowledge transfer is used to describe the movement of knowledge and is defined as "the process through which one unit (e.g., individual, group, or division) is affected by the experience of another" (Argote and Ingram, 2000, p.151). Knowledge transfer is based on the premise that knowledge can be easily transferred *without modification* and managed across organisational boundaries (Carlile and Rebentisch, 2003; Carlile, 2004). Knowledge transfer in university–industry collaborations mainly comprises the transfer of patents, licences, and scientific publications from universities to industry partners

(Cohen et al., 2002; Perkmann and Walsh, 2007; Hayter et al., 2020), of which some scholars have found that scientific publications are the most important form of knowledge transfer in university–industry collaborations (e.g., Cohen et al., 2002; Bekkers and Bodas Freitas, 2008). Critics of knowledge transfer argue that transferring knowledge is an inefficient approach to integrating knowledge when novelty and innovation are sought and the focal actors' knowledge bases are specialised, as knowledge is inherently personal and tacit and therefore not easily 'transferable' (Polanyi, 1967; Grant, 1996b).

Knowledge translating is often used to describe three related processes. The first process is (1) identifying differences and dependencies between partners, with university partners generally wanting to pursue academic publications, and industry partners typically wanting to create innovations (Johnson and Johnston, 2004; Bjerregaard, 2010). To handle these differences, two boundary-spanning approaches stand out in the literature, which comprise the second knowledge translating process, (2) creating shared meanings between partners (Kellogg et al., 2006; Carlile, 2004; Bechky, 2003) through close interaction over time (Steinmo, 2015; Bjerregaard, 2010) and negotiating differing interests and making trade-offs between partners (Carlile, 2004; Lander, 2016). Further, as university and industry partners have different knowledge bases (Perkmann, 2017; Miller et al., 2016), boundary spanners often need to undertake the third process – namely and (3) translating external domain-specific knowledge so that employees within the focal firm can understand it (Monteiro and Birkinshaw, 2017; Zahra et al., 2020).

Knowledge transforming is the process of altering existing knowledge and creating new knowledge (Carlile, 2002). As knowledge is inherently tacit (Polanyi, 1967), it is often challenging to transfer specialised knowledge from one domain and make it applicable to another domain. The literature often points towards boundary objects, such as tools, machines, numbers, blueprints, and prototypes, that can be used to learn about and transform knowledge between two domains (Carlile, 2002). Social interaction is thus deemed important in the process of transforming knowledge (Styhre, 2011; Carlile and Rebentisch, 2003), which implies that firms' boundary spanners need to interact closely with university researchers in research centres to transform and integrate individuals' specialised knowledge bases (Kellogg et al., 2006; Grant, 1996a) and solve challenges jointly (Gulbrandsen et al., 2015; Perkmann, 2017). Relatedly, Meyer-Krahmer and Schmoch (1998) and Monjon and Waelbroeck (2003) found that for firms, formal collaborations with universities are more important than passively receiving or acquiring publications and patents. Given that the transformation process requires time, actors' ability to integrate their knowledge is expected to improve with each iteration (Carlile and Rebentisch, 2003), which, in the context of university–industry collaborations, implies that partners will collaborate more effectively and generate better outcomes over time (Lauvås and Steinmo, 2019).

In summary, our review illustrates that the literature on university–industry collaboration has touched upon aspects of the three dimensions of knowledge integration, although indirectly. Further, prior research has indicated that individual engagement and commitment from industry-based boundary spanners are important for integrating knowledge from university partners (e.g., Santoro, 2000; Núñez-Sánchez et al., 2012). However, most studies on this topic do not go into detail about the underlying dynamics of collaborations, and to our knowledge, no studies have tried to reveal how the underpinning activities of transferring, translating, and transforming knowledge are actually carried out (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017; Hayter et al., 2020). Hence, to answer the calls (ibid.) for better operationalisations of knowledge

transferring, translating, and transforming, we pursued an in-depth abductive multiple-case study of how industry-based boundary spanners actually accomplish knowledge integration activities in research centres over time.

3 Methodology

3.1 Research design and cases

Given the limited theoretical and empirical evidence of how industry-based boundary spanners perform knowledge integration activities in research centres (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017; Langley et al., 2019), we conducted an abductive theory-building multiple-case study (Eisenhardt and Graebner, 2007). This method is particularly suited for process questions such as ours. Our setting is industry-based boundary spanners participating in six research centres operating from 2009 to 2015 under Norway's public Centres for Environment-Friendly Energy Research. The centres worked to develop environmental innovations in areas such as CO_2 storage, bioenergy, zero-emission buildings, offshore wind energy, and solar cells; had yearly budgets ranging from three to four million euros; and were funded by the Research Council of Norway (50%), university partners (25%), and industry partners (25%). Similar to other research centres in the European Union and the United States (Ponomariov and Boardman, 2010; Núñez-Sánchez et al., 2012; Lind et al., 2013), the centres had two main goals: (1) to develop knowledge and research at the international forefront that (2) the industry partners could then integrate into environmental innovations (Research Council of Norway, 2008).

Purposeful sampling was chosen to obtain an in-depth understanding (Patton, 2015). We contacted the six centre directors and asked for an interview and permission to study their research centres, which we were granted. After this interview, we asked for potential university and industry informants who could provide information about the collaboration process. To avoid relying solely on the centre managers' suggestions, we asked every subsequent interviewee to suggest other possible information-rich informants, whom we then recruited for the interviews (Patton, 2015). Hence, through snowball sampling, we chose informants within each of the six research centres and targeted 'key knowledgeables', which implied selecting university and industry informants who were engaged in the research centres with sufficient intensity to elucidate the collaboration process (Patton, 2015).

3.2 Data collection

We conducted 80 interviews with university and industry partners, which lasted an average of 75 min. The informants were first interviewed in 2013, with follow-up interviews in 2015 to uncover changes in their activities and to discuss topics of interest that arose from the analysis of the first-round interviews (Table 1). The interviews with the university partners provided multiple accounts of the same processes (Pentland, 1999), which decreased the risk of impression management bias (Eisenhardt and Graebner, 2007) and increased our contextual understanding.

Table 1 Data collection

	Sum
Informants (2013)	27 Firms*
	22 University partners**
Informants (2015)	14 Firms***
	17 University partners****
Total no. of interviews	80

Secondary sources: Annual reports, evaluation reports, firms' survey responses, websites, newsletters, press articles

*About half of the industry-based boundary spanners had a MSc degree, while the other half had a PhD. The informants' held the following positions: technical or R&D directors, senior advisors, researchers, or engineers.

**The people interviewed within each research centre often hold one of the following positions: centre manager, work package leader or researcher who worked in one or several work packages. Primarily, we interviewed centre leaders and work package leaders.

***13 out of 14 firms interviewed in 2015 were also interviewed in 2013.

****11 out of 17 university representatives interviewed in 2015 were also interviewed in 2013.

All industry informants in this study were considered to be engaged by the university partners, represented firms of various sizes, and reported outcomes regarding environmental innovations, knowledge, and networks according to the official midterm evaluations of the research centres (Research Council of Norway, 2013). We avoided interviewing bias by gaining access to midterm evaluations after conducting the interviews. The interview data were triangulated with secondary data sources (see Table 1) to understand how boundary spanners perform knowledge integration activities. As requested by the informants, the cases (and the contextual details provided in Section 4, 'Findings') are anonymised for confidentiality.

The interview guides were developed before commencing the interviews to explore the activities performed in the research centres and were based on secondary data, such as official annual reports (Yin, 2013). To account for the different perspectives of our informants, two separate semi-structured interview guides were applied: one for industrial partners and one for university partners. The interview guides were created to elucidate the collaboration process, because it seldom has been investigated (Perkmann and Walsh, 2007; Galán-Muros and Plewa, 2016). The interviews were conducted in chronological order, starting with the respondent's background and work relationships, followed by the initial stages of planning for the centre's activities and the level of involvement and the respondent's expectations at that stage. Further, the interviews covered their involvement in and experiences during the collaboration processes, innovation activities, suggestions for improvements, and their views on future collaboration. To avoid bias, we avoided the use of theoretical concepts in the interview setting (Yin, 2013). In this manner, we obtained the interviewees' narrative views of reality (Gephart, 2004). The follow-up interviews conducted in 2015 were designed to uncover any changes in collaborative dynamics that had occurred and to obtain additional information on topics of interest that arose from our analysis of the first interviews.

Two interviewers were present at all interviews to minimise bias, and we aimed to establish a conversational atmosphere in which the interviewees could speak as freely as possible (Patton, 2015). There were also situations in which we wanted the informants to provide additional details about key activities or unclear statements. In such situations, we asked follow-up questions, such as 'How did you do that', 'Why did you do that', 'Who was involved in that event', and 'When did this happen?' The interviews were recorded and transcribed verbatim during the data analysis process (Yin, 2013).

3.3 Data analysis

The data analysis process followed an abductive approach, developing from a more inductive analysis of the empirical data to more deductive matching and the development of the theoretical framework of knowledge integration. This abductive process is similar to the 'systematic combining' described by Dubois and Gadde (2002), in which empirical observations are used to expand and refine theoretical frameworks, aiming to match theory and reality. The abductive analysis process consisted of three main stages.

First, we read the interview transcripts multiple times and searched for broader patterns and insights into how the industry-based boundary spanners' involvement developed (Pentland, 1999; Yin, 2013). In this process, three time periods of the research centres were distinguished – establishment, performance, and end stages – which provided a temporal structure for our in-depth analysis. This is in line with Langley's (1999) temporal bracketing strategy, which is a way of structuring the description of events and analysis. Next, we identified that the boundary spanners' involvement and knowledge outcomes from the research centres varied. Thus, relevant codes and quotes concerning their involvement and knowledge outcomes were combined in a matrix over the periods (Miles et al., 2014) and were characterised into two main groups (Eisenhardt and Graebner, 2007; Pentland, 1999) – boundary spanners and (1) firms with some involvement and few knowledge outcomes and (2) firms with high involvement and many knowledge outcomes. The interviewees were almost evenly divided between these two groups (see Table 2).

Second, qualitative analysis software (NVivo 12) was used next to facilitate the coding and categorisation of the knowledge integration activities that each of the industry-based boundary spanners carried out. The coding consisted of data-driven inductive (sub-)codes (e.g., suggesting research activities) (Langley, 1999) and included critical characteristics and activities related to the boundary spanners' involvement. Subsequently, we identified similar codes and clustered them into first-order concepts before searching for linkages among the concepts, which led to the development of second-order analytical themes (Gioia et al., 2013). During this process, we also observed that the knowledge integration activities were performed internally in the firms and/or externally towards the research centres to create environmental innovations. The purpose of this enquiry was an in-depth exploration of the boundary spanners' activities relating to knowledge integration with the aim of building theory (Eisenhardt and Graebner, 2007).

Hence, the third and final step was more theoretically driven, seeking a match as well as contradictions with the empirics and existing theories (Dubois and Gadde, 2002; Eisenhardt, 1989), which involved an in-depth exploration of the literature on boundary spanning (e.g., Perkmann, 2017; Birkinshaw et al., 2017) and knowledge integration (e.g., Grant, 1996a; Tell et al., 2017). In this process, we reviewed the extant literature to

identify theoretical concepts that could explain our findings (Eisenhardt, 1989), finding that the knowledge integration dimensions of transferring, translating, and transforming (Carlile, 2004; Van de Ven and Zahra, 2017) were suitable. Hence, in the final step, we assembled the second-order themes into the aggregate dimensions of knowledge transferring, translating, and transforming (see Figure 1). Further, Figure A1 (Appendix) presents the emergent data structure, including the boundary spanners' first-order quotations.

4 Findings

We present our findings in two sections. First, we provide an overview and classification of the industry-based boundary spanners' involvement in and knowledge outcomes from the research centres. Second, we present the findings regarding the knowledge integration activities in the research centres and compare how these activities relate to the highly involved and less involved boundary spanners.

4.1 Generating knowledge outcomes from the research centres

We found that the firms and industry-based boundary spanners belonged to two main groups regarding involvement and knowledge outcomes from the research centres. Unsurprisingly, the highly involved boundary spanners (BS 13–28) and their firms achieved more knowledge outcomes from the research results in both periods (Table 2) compared with the less involved spanners (BS 1–12), confirming that involvement and commitment are important premises for successful university–industry collaborations (Santoro, 2000; Mora-Valentin et al., 2004; Núñez-Sánchez et al., 2012).

Table 2 Boundary spanners' involvement in and knowledge outcomes from the research centres

Industry-based boundary spanner	*Involvement**	*Knowledge outcomes***
Some involvement in and few outcomes from the research centre	Some: "I struggle to be involved in the research activities and, at the same time, handle the daily operations" (BS1) 'We were not actively involved in setting the research agenda… It was at the bottom of our priority list" (BS2) 'I have discussed the research development [with the university partners] ... but I could have been more involved" (BS3) "It could have been a closer collaboration" (BS4) "We are rather passively following up [with] the centre" (BS5)	Few: "The research is not relevant" (BS1) "Frankly, we haven't gotten any results… The output is marginal" (BS2) "We did some tests, but with no useful results…We did not follow up as closely as we should have" (BS3) "We hoped to get more outputs" (BS4) "We have increased our knowledge base and networks from participating in the centre" (BS5)

Table 2 Boundary spanners' involvement in and knowledge outcomes from the research centres (continued)

Industry-based boundary spanner	*Involvement**	*Knowledge outcomes***
High involvement in and many outcomes from the research centre	High: "We have continuously provided input about the research focus of the centre" (BS13) "We have been involved in setting the research agenda" (BS14) "We have been active towards the centre…using the centre to test and develop our technology" (BS15) "We are very involved… We have demonstrated new knowledge, and we give instructions on what we believe is important for the university partners to focus on" (BS16) "We work very closely with the university partners…It is formal and informal interactions weekly" (BS17)	Many: "We have gotten quite exciting results. [The technology] worked surprisingly well, or very well" (BS15) "What we know now, compared to four years ago, is "two different worlds"… We have come much further than we would have done without them [university partners]" (BS14) "We have gained knowledge and a very good understanding about the industry. We are now ensured that our [commercial] focus is right" (BS13) "We would not have succeeded if we hadn't participated in the research centre…Many have said that this is impossible…but we show that it is actually possible" (BS16) "We need the knowledge generated in the research centre to optimise our [product]…and we got very good results" (BS17)

*Based on illustrative quotes from the boundary spanners in this study.

**Based on illustrative quotes from the boundary spanners in this study and answers in the midterm evaluations related to how the centres' activities have benefitted the firms regarding innovations, knowledge, and networks.

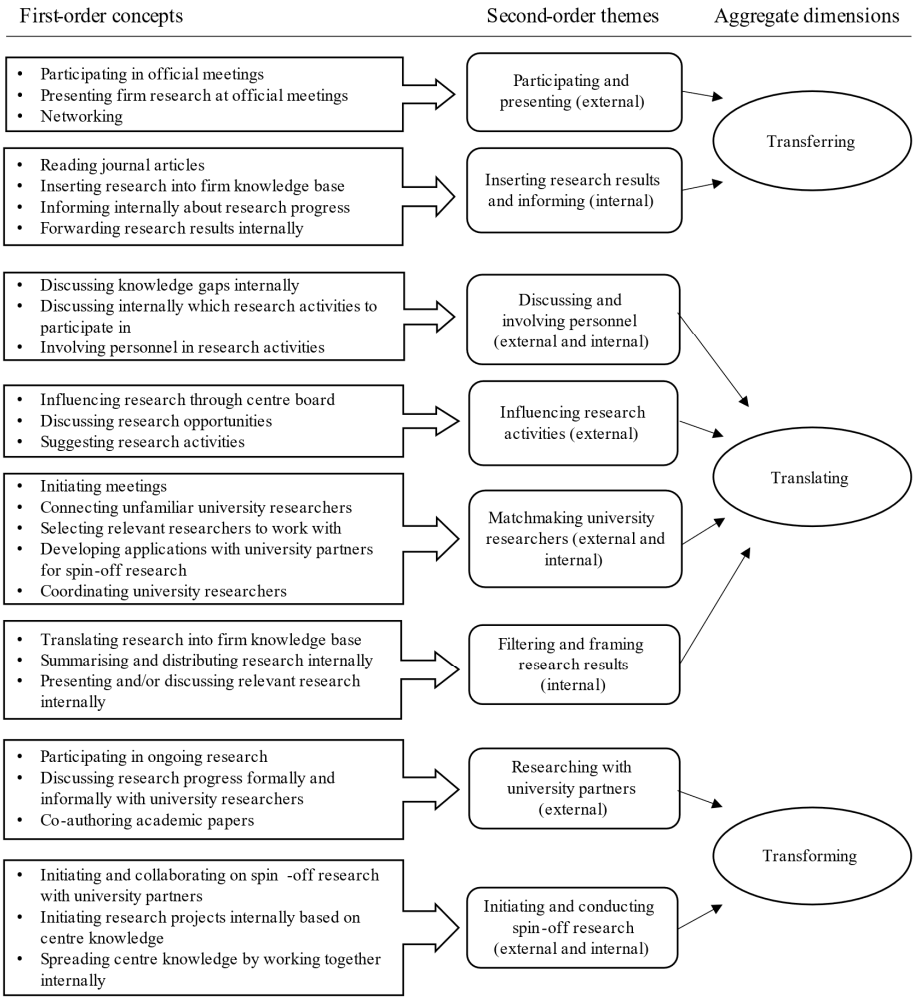
4.2 Boundary spanners' knowledge integration activities in research centres

Overall, we found that the boundary spanners in this study performed a diverse set of transferring, translating, and transforming activities (Carlile, 2004) externally towards the university partners and internally in their focal firms (see Figure 1).

4.2.1 Knowledge transferring

We identified two knowledge transfer activities that the industry-based boundary spanners performed, through which knowledge was more or less easily transferred (Carlile and Rebentisch, 2003; Carlile, 2004) between the university and firm partners without requiring many resources from the boundary spanners.

Figure 1 Data structure – Boundary spanners' knowledge integration activities in research centres



Participating and presenting (external)

All the boundary spanners in this study participated externally in official meetings and seminars arranged by the university partners, with the highly involved spanners also presenting their firms' research. Such events were important for the boundary spanners to obtain an overview of current and potential research activities and to present their firms' R&D activities and firm data that the research centres could potentially work. Moreover, these meetings were important arenas for establishing and strengthening social relations between the partners, as exemplified by a highly involved boundary spanner: "The physical meetings and conferences are important… We have presented some of our R&D projects there, which has spurred interesting discussions with to possible university and firm partners" (BS23). The group of highly involved boundary spanners participated in these conferences more actively and used their time in the spotlight to network and present their firms' research, whereas the less involved boundary spanners often

participated as passive receivers, as evidenced by a less involved boundary spanner: "[These conferences'] attendance is to keep myself oriented. It is often interesting to listen to [the university researchers]… but it is not always relevant for our business" (BS9).

Inserting research results and informing (internal)

We found that the university partners often finalised publications and reports at the end stage of the research centres and made these available to the firm partners. However, few boundary spanners in this study managed to simply 'transfer' the research results obtained from their university partners into their firms, as exemplified by a boundary spanner: "I often get an email about new publications and updates… I have sometimes forwarded relevant knowledge to other employees, but they probably don't read it… I'm not sure they have the time or capacity" (BS1).

A few exceptions were observed in which the boundary spanners were able to insert the research results directly into their internal knowledge bases. For example, one boundary spanner explained, "The research centre serves as a "filter" of research results for us… That has been a big advantage for us… We can then just insert this knowledge into our models" (BS24). Hence, filtering and framing of the university partners' specialised knowledge were often required for useful internal firm use (as discussed below).

4.2.2 Knowledge translating

We identified four knowledge-translating activities that the industry-based boundary spanners performed to involve relevant firm and university expertise, make the specialised knowledge provided by the research centres more understandable internally, and handle institutional differences between the university and industry partners.

Discussing and involving personnel (external and internal)

We found that in creating a fit between the research activities in the research centres and the knowledge needs of the firms, all the highly involved and some of the less involved industry-based boundary spanners initiated internal discussions regarding the centres' research activities and developments, as one boundary spanner stated: "We have discussed [internally] what knowledge gaps we have and what we want the research centre to focus on" (BS20). Furthermore, some of the highly involved boundary spanners benefitted from identifying and involving other firm personnel with relevant expertise in the research centres' activities. For example, a highly involved boundary spanner identified relevant meetings for other firm employees to participate in: "The technical insights of the research results come in the technical subject meetings, and at a meeting two weeks ago, I brought with me "the others" [who work in that subject area]" (BS24).

However, the less involved boundary spanners tended to operate single-handedly towards the research centres and struggled to involve other firm personnel, as one such boundary spanner noted: "We are an operative organisation; we focus on operations… I'm therefore solely following up [with] the research centre" (BS 11). One of the centre managers commented on this issue: "The challenge is that they [boundary spanners] often do not have inhouse expertise that they can communicate… that matches what happens in this research centre". A less involved boundary spanner agreed with this sentiment:

"I have too few internal resources [personnel] in the organisation that I can use towards the research centre, which hampers our ability to follow up [with] the centre as well as we would like" (BS9).

Influencing research activities (external)

Based on the involvement and views of several firm employees, the most involved boundary spanners were very active in influencing research activities in the research centres. For example, one highly involved boundary spanner explained, "We [the firm] had a lot of specific knowledge gaps that we suggested as possible research activities that were discussed with other firms and university partners. Now, something is solved, and some aspects are still "works in progress" on which we expect to give valuable insights" (BS 18). Such active involvement was also acknowledged and desired by the centre managers, as one manager noted: '"Professional discussions" are a really effective way of influencing because, there, you [boundary spanner] can present your ideas to the university partner, which then could reply with his research suggestions, and you could have a match'. A highly involved boundary spanner confirmed this view: 'We have influenced the research activities… so the research is of interest to us… and to them [the university partners]… We have compromised on a range of research areas' (BS22).

The less involved boundary spanners were somewhat active in influencing and suggesting research activities to the research centres but often failed to suggest activities that were relevant for the researchers and seldom followed up on their suggestions. However, a few exceptions were observed in the end stage of the centres, where some boundary spanners acknowledged that they had to be involved more in these activities if the research results were to be useful for their firms. According to one boundary spanner, "We now [end stage] discuss the work plan [with the university partners] on what is planned, what is important for us and how the resources can be dedicated" (BS1). Consequently, the research centres' activities became more relevant for these firms, as the boundary spanner further explained: "It is now more thought through what they [the university partners] should do research on, and it "works" … These results can be used to improve the industry's facilities" (BS1). Another observation relates to how several of the less involved boundary spanners missed out on opportunities to influence the research activities. For instance, one boundary spanner told us the following: "I just had a meeting with the university researchers about future research activities that they wanted input on… but I wasn't really prepared" (BS4).

Matchmaking of university researchers (external and internal)

We found that the boundary spanners in this study managed to connect and coordinate external researchers in the research centres (matchmaking) towards their firms in three ways that benefitted both the firms and university partners. First, a few of the boundary spanners conducted, quite surprisingly, matchmaking activities that mainly benefitted the university researchers. These boundary spanners managed to identify and connect unfamiliar university researchers that they believed had the potential to create valuable research results, as one boundary spanner explained: "We connected some researchers. They worked on similar research questions but from different angles… I do not think that [university researcher collaboration] would have happened without us suggesting that they should talk together" (BS2).

Second, some boundary spanners identified key persons in their firms and connected those persons with university researchers who needed access to unique firm data that were later used for research purposes. As one boundary spanner reported, "We helped the centre management [with data access]… and put them in contact with the right decision makers in our firm" (BS26).

Third, most of the highly involved boundary spanners became very familiar with the university researchers, which enabled them to select university researchers with relevant knowledge according to their specific firm needs. This approach was evidenced well by one boundary spanner: "I hand-picked resources from [the research centre], and when I needed competence in [subject area a, b, or c], I drew on interdisciplinary knowledge from other work areas. That worked very well… It would be difficult without this kind of active coordination" (BS14).

Filtering and framing of research results (internal)

Many of the boundary spanners in this study were actively involved in filtering, which involved assessing and selecting relevant research from a range of research results, and framing, which involved converting the 'language' of the research results into a more understandable and useful form for the firms. The boundary spanners engaged in filtering and framing, mainly by discussing relevant research results internally and by translating the research results into their firms' knowledge bases. For instance, one boundary spanner explained, "We have an internal system with documentation and knowledge… Sometimes you can just cut and paste, but most often, you need to translate the results to become relevant for the firm. In that process, we use research results combined with our internal [firm] knowledge" (BS24). The filtering and framing of research results also often facilitated better internal coordination, which generated new possibilities for spin-off research projects, as exemplified by a boundary spanner who, over time, developed a better system for filtering and framing: "We now [end stage of the research centre] have much better internal coordination… The research projects and reports are collected and categorised, which we can later discuss and collaborate on internally" (BS1).

4.2.3 Knowledge transforming

We identified two activities that the industry-based boundary spanners performed to create new knowledge based on the university's and industry partners' specialised knowledge bases (Carlile, 2002).

Conducting research together with university partners (external)

Our data show the importance of boundary spanners conducting research together with university partners for the creation of new knowledge. To do so, the boundary spanners participated in ongoing research and discussed research progress formally (e.g., meetings and workshops) and informally (e.g., phone calls) with the university researchers. The highly involved boundary spanners were closely involved in these activities, as noted by one boundary spanner: "We work very closely with [the university partners]. We are here [at the university] at least three times a week, so we have a close dialogue" (BS17). Similarly, another boundary spanner explained that "research with university partners is really important for the firm" (BS21). Another highly involved boundary spanner explicated the importance of conducting research with university partners and illustrated

how their industrial processes are used as 'boundary objects' to transform knowledge (Carlile, 2002): "It has been great to get the [university partners] to research and document the "processes" thoroughly. We had previously searched in academic papers… but that was of low quality… Now, we have accomplished that in collaboration with [the university partners]" (BS16). The less involved boundary spanners had little involvement in these activities, as noted by one such boundary spanner: "I don't have time to work on, or follow up with, the research subjects" (BS4). Ultimately, this lack of involvement hampered knowledge transforming.

Initiating and conducting spin-off research projects (external and internal)

Our data show that knowledge transforming is a long-term process that requires additional research activities to reach its potential. As such, together with the university partners, the most involved boundary spanners initiated spin-off research projects based on knowledge produced in the research centres but focusing more on firm-specific issues. For example, one boundary spanner explained the following:

> "Much effort goes into spin-off projects that are connected to the research centre, which has been central, especially on [subject X]. Within [subject Y], it has been crucial… I find that we learn a lot by working together. Until now, there has been little knowledge in our area, but we are getting there in collaboration with [the university partners]… We do things that nobody else has done before". (BS18)

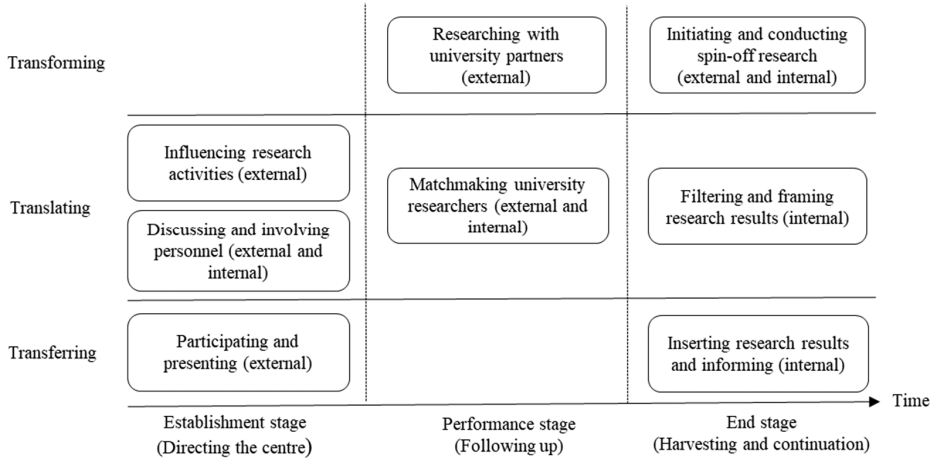
Our data further illustrate that the research centres functioned as knowledge bases that the highly involved industry-based boundary spanners were able to use as a basis for more applied spin-off research projects. Indeed, one boundary spanner noted, "A large amount of basic research has been done that we now are harvesting, creating a lot of interesting applied results through the spin-off project" (BS27). Some of these boundary spanners also initiated new research projects internally in their firms, as another boundary spanner explained: "We try to integrate knowledge [from the centre] within the firm by working together on projects" (BS21). Hence, some of the boundary spanners spread and integrated tacit knowledge from the centres internally by working closely with other employees within their firms, as explained by another boundary spanner: "I try to share what I have learned [from the centre] internally through projects" (BS25).

5 Discussion

Based on the findings presented in Section 4, we develop a conceptual framework (Figure 2) outlining a pattern by which knowledge integration activities are performed by industry-based boundary spanners across three different stages of a research centre, of which prior literature has seldom distinguished (Skute et al., 2019). Although the overall framework is the same, we outline several key differences in how highly and less involved industry-based boundary spanners integrate knowledge from research centres over time. Therefore, our research contributes to the recent literature on how firm involvement and commitment may be set into action (Santoro, 2000; Núñez-Sánchez et al., 2012; Lauvås and Steinmo, 2019) to realise environmental innovations (Harryson et al., 2007; de Wit-de Vries et al., 2019) and, in particular, to the debate on how boundary spanning and knowledge integration are performed (Le Dain and Merminod,

2014; Van de Ven and Zahra, 2017; Langley et al., 2019). The underlying basis for this discussion is the realisation that the institutional logics of university and industry partners differs (Bjerregaard, 2010), and that firms need to take action to tackle different organisational goals, motivations, time horizons, etc. that they face in a collaboration (Hounshell and Smith, 1988; Estrada et al., 2016; Galán-Muros and Plewa, 2016).

Figure 2 Boundary spanners' knowledge integration activities performed across different stages of a research centre



Numerous frameworks for knowledge integration have been suggested (e.g., De Boer et al., 1999; Grant, 1996b; Miller et al., 2016), but few of them offer an integrated theoretical framework based on empirical data. As such, this study builds on the theoretical framework of (Carlile, 2004) and suggests a more nuanced set of activities underpinning knowledge transferring, translating, and transforming and identifies a pattern on how they are performed by boundary-spanners across different stages of a research centre. With this, we also contribute to a more holistic and dynamic knowledge of absorptive processes, whereby knowledge integration is considered a theoretical foundation (Song et al., 2018). The following paragraphs present our framework in detail with reference to Figure 2.

5.1 Boundary spanners' knowledge integration activities performed across different stages of a research centre

We identified three key activities in the establishment stage (before centre initiation and during the first year) that enabled the boundary spanners to direct the research focus of the centres and acted as the foundation for other activities in later stages. First, our data suggest that firms' *participation in and presentations at* official meetings and seminars were important arenas for establishing and strengthening social relations with the university partners, which was found to be a prerequisite for further collaboration (Lauvås and Steinmo, 2019). Accordingly, the boundary spanners who actively participated in such formal meetings and seminars (Morandi, 2013) were more able to build momentum regarding their firms' research activities.

Second, our findings illustrate a vast difference regarding the ability of boundary spanners to *discuss and involve personnel* from their firms with university partners. Based on internal discussions and involvement, the highly involved boundary spanners were more likely to create a larger pool of research possibilities and achieve momentum regarding their research interests, thus enabling these boundary spanners to *influence the research activities* of the research centres. Our findings thus illustrate how the highly involved boundary spanners actively discussed research questions with their university partners and considered both parties' interests, which have been found to be major challenges in university–industry collaborations (Perkmann and Walsh, 2007; Bjerregaard, 2010). Moreover, in contrast to previous studies advocating the importance of creating shared meaning between collaborative partners in general (e.g., Carlile, 2004; Bechky, 2003) and in university–industry collaborations in particular (Bjerregaard, 2010; Steinmo, 2015), our findings are consistent with research suggesting that shared meaning is not essential because partners can reach agreement about common activities despite having opposing meanings (Kellogg et al., 2006; Lander, 2016), and that this often happens through informal dialogue (Morandi, 2013).

Regarding the less involved boundary spanners, our findings illustrate their struggle in involving other firm personnel, which is in line with and extends the findings by Santoro and Chakrabarti (2002): these boundary spanners missed out on opportunities to influence the centres' research activities. Further, our findings exemplify several missed translation opportunities, such as a lack of ideas for research activities that could have influenced the activities of the research centres, hampering the knowledge integration process (Carlile and Rebentisch, 2003; Carlile, 2004). These findings illustrate the importance of directing research centres, thus confirming the importance of commitment and involvement by boundary spanners over time (Santoro, 2000; Mora-Valentin et al., 2004; Núñez-Sánchez et al., 2012). Hence, we confirmed and extended Jarvenpaa and Valikangas (2016) findings by suggesting that firms that are involved in and dedicate resources to a research centre over time are better able to influence the centre's research agenda.

Next, our findings demonstrate that influencing and suggesting research activities enabled the boundary spanners to conduct *research together with the university partners* within the research centres during the performance stage (during the collaborations). This stage entailed follow-up research activities whereby the boundary spanners could participate in ongoing research and discuss research progress formally and informally with the university researchers. Our data thus demonstrate the importance of firms conducting research together with university partners for the creation of new knowledge (Grant, 1996b; Styhre, 2011), which is in line with scholars advocating that engaging in formal collaborations is more important for firms than passively receiving or acquiring publications and patents (Meyer-Krahmer and Schmoch, 1998; Monjon and Waelbroeck, 2003). Another important aspect is that our data further illustrate how the highly involved boundary spanners were able to conduct research together with the university partners that was relevant both for their firms and the university partners, which has been deemed the biggest challenge in university–industry collaborations (Perkmann and Walsh, 2007; Galán-Muros and Plewa, 2016; Lauvås and Steinmo, 2019).

Moreover, our findings suggest that during the research process, the industry-based boundary spanners with the most knowledge outcomes invested time in getting to know their partners in terms of competence and research expertise, which laid the foundation for *matchmaking university researchers* (Monteiro and Birkinshaw, 2017) for new

research projects that benefitted both the firms and university partners. Hence, our findings add nuance to the finding that successful industry partners often have social proximity with their university partners (Jakobsen and Steinmo, 2016; Lauvås and Steinmo, 2019), illustrating that boundary spanners can draw upon and select university researchers for their spin-off research projects.

Relatedly, at the end stage (during the last year[s] of the centres), we observed that the highly involved boundary spanners were able to 'harvest' their matchmaking activities by selecting relevant university researchers with whom to *initiate and conduct spin-off research projects* based on the knowledge developed in the research centres. Some of these boundary spanners also initiated new research projects internally in their firms, thus spreading and integrating tacit knowledge from the centres. In this matter, the boundary spanners sought to integrate the tacit knowledge (Polanyi, 1967) they had generated in the research centres. Hence, our findings illustrate how research projects can be further developed into new projects, both internally in firms and with university partners, which has received limited focus in the innovation literature (Dimos and Pugh, 2016).

Furthermore, in line with Hoffmann et al. (2017), we found that publications and reports were often finalised by the university researchers at the end stage and made available to the firm partners. When research results from the research centres became available, we observed that only a few of the boundary spanners were able to conduct the transfer activity of *inserting research* into their firms' knowledge bases and *internally informing* their firms. Due to the complex nature of academic research (Galán-Muros and Plewa, 2016), boundary spanners often needed to conduct *filtering and framing* to ensure that the results were relevant and understandable for internal firm applications.

Hence, in contrast to scholars who have found scientific publications to be the most important form of knowledge transfer in university–industry collaborations (Cohen et al., 2002; Bekkers and Freitas, 2008), our findings illustrate that the knowledge bases of university and industry partners may be so specialised (Perkmann, 2017) that a pure knowledge transfer process may not be able to address the differences and dependencies among all actors (Polanyi, 1967; Grant, 1996b) and thus requires filtering and framing of research results for internal use. As such, our findings illustrate that translating research results is a more active form of knowledge integration and demands greater effort from boundary spanners than knowledge transfer activities (Carlile, 2004). Our findings thus add nuance to prior research, which has seldom scrutinised how firms can benefit from knowledge outcomes from university–industry collaborations (Cohen et al., 2002; Bekkers and Bodas Freitas, 2008), by showing that knowledge translating through filtering and framing is necessary for firms to obtain value from academic publications in such collaborations.

In summary, this study builds theory by providing a more nuanced set of knowledge activities underpinning the dimensions of transfer, translation, and transformation (Carlile, 2004; Van de Ven and Zahra, 2017). We thus go beyond much of the knowledge transfer literature that has mostly treated this concept as one dimensional (e.g., Argote and Ingram, 2000). The empirics from the six research centres and the pattern illustrated in Figure 2 further suggest that to successfully integrate specialised knowledge from university partners required for environmental innovations, boundary spanners cannot expect to engage in the highest value-adding activities of knowledge transforming (Monteiro and Birkinshaw, 2017; Grant, 1996b) without first engaging in transferring and translating activities. Thus, these findings provide guidance on how industry-based

boundary spanners can, over time (Skute et al., 2019), take action when collaborating with university partners (Perkmann and Salter, 2012) to integrate their specialised knowledge into environmental innovations (De Marchi, 2012; Jakobsen et al., 2019).

6 Conclusion and implications

This study offers detailed evidence of how industry-based boundary spanners integrate specialised knowledge from research centres into their firms to create environmental innovations (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017; Hermundsdottir and Aspelund, 2021).

Numerous studies have shown the importance of firm involvement when collaborating with universities to achieve innovation outcomes (e.g., Santoro, 2000; Núñez-Sánchez et al., 2012), whereas few have focused on *how* firms should be involved in these collaborations to realise outcomes, such as environmental innovations (Harryson et al., 2007; de Wit-de Vries et al., 2019). We overcome this shortcoming and contribute to the debate on the dynamic relationship between environmental innovation partners (Yarahmadi and Higgins, 2012; De Marchi, 2012; Jakobsen et al., 2019) by exploring activities performed by industry-based boundary spanners involved in research centres, who are the key enablers for integrating specialised knowledge from university partners. As such, we provide two key contributions.

First, we propose that boundary spanners should perform transferring, translating, and transforming activities to create environmental innovations (Carlile, 2004; De Marchi, 2012) and identify underpinning activities for knowledge integration that are performed internally in their firms and externally towards research centres (Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017). On a theoretical note, this articulation adds to the literature, which has paid little attention to and has called for more research on the dimensions of knowledge integration (Carlile, 2004; Le Dain and Merminod, 2014; Van de Ven and Zahra, 2017). Second, we illustrate how firms can take action when collaborating with university partners (Harryson et al., 2007; Perkmann and Salter, 2012) by revealing a pattern in how boundary-spanning activities may be attended to in the establishment, performance, and end stages of a research centre (Skute et al., 2019). As such, we extend Carlile (2004) theoretical framework by showing that boundary spanners cannot expect to engage in the highest value-adding activities of transforming knowledge (Monteiro and Birkinshaw, 2017; Grant, 1996b) without first engaging in transfer and translation activities. Thus, we provide insights into the absorptive processes leading up to innovation (Song et al., 2018).

6.1 Implications

Studying industry-based boundary spanners' activities for knowledge integration in research centres is necessary not only to fulfil our academic need for knowledge but also for firms seeking to create environmental innovations based on specialised knowledge. Hence, our findings have important implications for industry partners involved in research centres aiming to realise environmental innovations and for policymakers who fund such collaborations. As firm involvement is an important premise for successful collaborations with university partners (Santoro, 2000; Mora-Valentin et al., 2004; Núñez-Sánchez et al., 2012), our study provides insights into the processual elements of

how firms can be involved and take action to participate in useful collaborations. Our findings demonstrate a range of knowledge integration activities (Le Dain and Merminod, 2014; Hayter et al., 2020) that are performed internally in firms and externally towards research centres and offer guidance for boundary spanners on how to perform these activities in the three stages of a research centre: establishment, performance, and end stages. With this, we contribute important insights to the literature on environmental innovations, which has called for insights into how these innovations develop (Hermundsdottir and Aspelund, 2021).

Moreover, prior research has found that many firms that engage in collaborations with university partners exhibit low involvement (Santoro and Chakrabarti, 2002). However, our findings imply that firms should provide resources and time to their boundary spanners in all stages of a research centre to be able to operate and mediate both in their firms and towards the research centres to achieve the most knowledge outcomes from research centres. Our findings also imply that formalising university–industry collaborations through a research centre does not automatically lead to increased firm involvement (Thune and Gulbrandsen, 2014). Hence, university partners should be motivated to involve industry partners early on and during their collaborations to perform the activities needed for environmental innovations.

Our findings also have important implications for policymakers. Given that many policy initiatives take a technology- and knowledge transfer perspective (Broström et al., 2020), a shift to a broader focus taking into account the need for knowledge translating and transforming is necessary. Hence, policymakers could stimulate and facilitate the knowledge integration activities found in this study to foster environmental innovations. However, patience is necessary because it takes time for boundary spanners to become involved in the activities required to integrate the specialised knowledge needed for such innovations. A related note is that although our focus and context are environmental innovations, we propose that these knowledge integration activities would play out in a similar fashion for general innovations.

6.2 Limitations and future research

This study has limitations that provide opportunities for future research. First, this study is limited to the knowledge integration activities performed by individuals in firms that engage with university partners, and only concerns individuals who represent the university side of such collaborations to a limited extent. The latter have been found to be important actors in knowledge integration in large-scale university–industry collaborations (Knudsen et al., 2017). Future research could therefore demonstrate the 'two-way' interaction process in university–industry collaborations (Meyer-Krahmer and Schmoch, 1998; Meng et al., 2019) by capturing the university side as well. Second, our purposeful sampling of industry-based boundary spanners offers depth at the cost of breadth. Thus, our findings should be tested in large-scale surveys. Relatedly, the knowledge integration activities addressed in Figure 1 combined with the insights from Figure 2 could be used in quantitative studies as indicators of industry involvement, similar to Bozeman and Gaughan (2007), who explored the involvement of university researchers with industry partners.

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Note

[1]An exception is the work by Grant (1996b). However, this framework assumes that the primary role of a firm is to apply existing knowledge in the production of goods and services and is therefore too heavily based on 'routine activities' to be empirically relevant for the context of university-industry collaborations as their goal is to create new knowledge and innovations.

Appendix

Figure A1 Data structure: Representative quotations

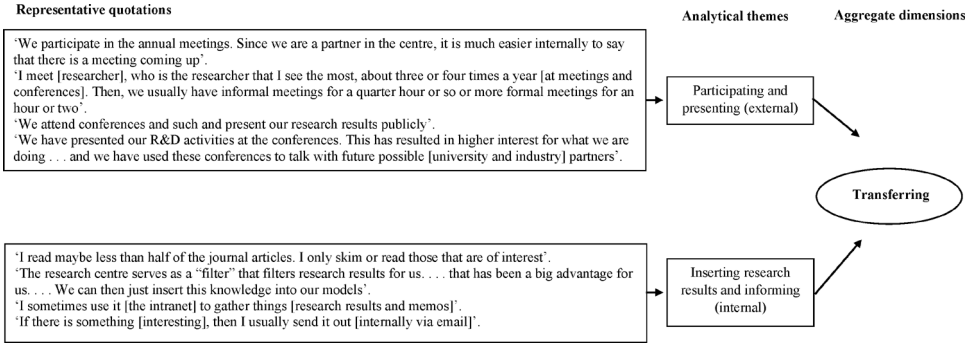

Figure A1 Data structure: Representative quotations (continued)