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Framing and Interorganizational Knowledge Transfer: A Process Study of Collaborative Innovation in the Aircraft Industry[1]

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Abstract

This article explains how and why organizational actors' decisions about interorganizational knowledge transfer might change over time. We find that organizational actors' framing of future innovation developments, as either an opportunity or a threat, motivates them to engage or disengage in interorganizational knowledge transfer activities. Shifts in framing lead organizational actors to leverage their relational context and knowledge base in new ways, thereby emphasizing the role of agency in drawing upon these structures. These findings are incorporated into a process model that explains discontinuous change in interorganizational knowledge transfer.

Keywords: framing; innovation; interorganizational knowledge transfer; process

When organizational actors share and trade knowledge in interorganizational collaborations they do so because of the benefits of knowledge transfer, such as enhanced innovativeness (Powell et al., 1996; Van Wijk et al., 2008). But we also know that actors prevent or reduce knowledge transfer to avoid spillovers of critical know-how (Khanna et al., 1998; Norman, 2004). A theory of interorganizational knowledge transfer therefore needs to explain both decisions of organizations to initiate or intensify as well as decisions to reduce or terminate knowledge transfer. However, currently we lack proper understanding of how these decisions can change over time.

In this paper, we develop such an explanation of the dynamics of interorganizational knowledge transfer over time. Most research into interorganizational knowledge transfer uses cross-sectional methods to explain the amount of knowledge transfer in a given partnership (Meier, 2011; Parmigiani and Rivera-Santos, 2011; Van Wijk et al., 2008). Thus, existing explanations focus mainly on the characteristics of the organizational actors engaged in knowledge transfer (e.g., willingness to share, absorptive capacity), the nature of their relationships (e.g., relationship quality, governance mechanisms), and the knowledge involved (e.g., tacitness) (Easterby-Smith et al., 2008; Meier, 2011). Yet, these cross-sectional studies have not traced or explained decisions of organizations to initiate, intensify, reduce or terminate knowledge transfer. Understanding such changes over time is important, especially in the protracted and emergent journey of an innovation process (Van de Ven et al., 1999), involving multitudinous decisions on knowledge transfer. Therefore, we address the following research question: *How and why do organizational actors' decisions about interorganizational knowledge transfer change over time?*

To address this question, we undertook a longitudinal study of the development of a new class of aircraft materials, fiber metal laminates (FML), whose development spanned more than two decades of knowledge transfer interactions, involving more than 20 organizations.

Using a process study (Langley, 1999; Van de Ven, 2007), we investigate patterns in knowledge transfer over time. The analyses show that decisions to initiate, intensify, reduce or terminate knowledge transfer often depend on the framing of future innovation developments, whether as opportunity or threat. Therefore, we invoke cognitive framing theory to explain actions on the basis of the way managers and organizations make sense of their environment (Dutton and Jackson, 1987; Kaplan, 2011).

In turn, our findings contribute to current theory on knowledge transfer and cognitive framing in three ways. First, we explain how discontinuous changes in interorganizational knowledge transfer (i.e., initiating, intensifying, reducing, or terminating knowledge sharing) are shaped by the actors' future-oriented framing of the innovation. These frames are both long-term oriented and variable, such that changes in their framing motivate actors to adjust their interorganizational knowledge transfer activities. Second, the shifts in framing also lead organizational actors to leverage their relational context and knowledge base in new ways, thus emphasizing the role of agency instead of knowledge transfer solely determined by these antecedents. Accordingly, we clarify the dynamics of interorganizational knowledge transfer by explaining why and when organizational actors might decide to initiate, intensify, reduce or terminate their knowledge transfer interactions with existing and new partners. Third, our findings extend cognitive framing theory by demonstrating the influence of not only threat and opportunity frames on decision-making, but also that of unframing opportunities.

THEORETICAL BACKGROUND

Firms need interorganizational connections to gain access to complementary knowledge resources. Both vertical (buyers and suppliers) and horizontal (competitors or other partners) collaborations are valuable: Customers can help define market needs (Von Hippel, 1986), suppliers provide long-term access to specialized and complementary assets (Lipparini et al., in press; Van Echtelt et al., 2008), and competitors offer opportunities to learn new skills and access to needed assets (Ahuja, 2000; Mowery et al., 1996). We thus define interorganizational knowledge transfer broadly, as the process by which organizations exchange knowledge, receive knowledge, and are influenced by the knowledge of others (Easterby-Smith et al., 2008; Phelps et al., 2012; Van Wijk et al., 2008).

Following prior studies and reviews (Argote et al., 2003; Easterby-Smith et al., 2008; Inkpen, 2002; Meier, 2011; Phelps et al., 2012), we model interorganizational knowledge transfer as a process that involves organizational actors as sources and recipients, influenced by their relationships and the characteristics of the knowledge. A single organization may participate as both a knowledge source and a knowledge recipient, because interorganizational knowledge transfer is often reciprocal (Kachra and White, 2008; Lipparini et al., in press) and may involve frequent interactions to integrate more tacit knowledge for the joint development of new knowledge (Hardy et al., 2003). We acknowledge that the concept of knowledge transfer seems to reify knowledge as an entity, but we follow others in using this concept as a shorthand expression for a process that is more complex and interactive (Easterby-Smith et al., 2008; Huxham and Hibbert, 2008).

Prior studies explored the effects of relational, knowledge, and organizational characteristics on interorganizational knowledge transfer, typically as antecedents that might explain variance in the amount of knowledge transfer in a given alliance. In studies that focus on interorganizational knowledge transfer, most attention centers on the effects of the *relational context*, including relationship quality and governance mechanisms (Phelps et al., 2012). High quality relationships – often referred to as strong ties – are characterized by trust and shared understanding, and increase the amount of knowledge sharing in established collaborations (Becerra et al., 2008; Kale et al., 2000; Van Wijk et al., 2008; Yli-Renko et al., 2001). Arduous relationships and conflict instead offer negative antecedents of knowledge transfer (Ko et al., 2005; Tsang et al., 2004). Moreover, strong ties predict renewed cooperation in the future (Gulati and Gargiulo, 1999; Powell et al., 1996). Finally, knowledge alliances likely result in positive learning outcomes when partners have appropriate governance mechanisms, such as formal contracts, to enable both knowledge sharing and knowledge protection (Dyer and Singh, 1998; Mohr and Sengupta, 2002; Parmigiani and Rivera-Santos, 2011).

Characteristics of the organizations' *knowledge base* also influence knowledge transfer (Van Wijk et al., 2008). In particular, the tacitness of partner knowledge hampers interorganizational knowledge transfer, because tacit knowledge requires more intensive interactions before it can be understood and incorporated (Becerra et al., 2008). Further, the formal appropriability of knowledge, as established by intellectual property rights (IPR) such as patents or copyright protection, enables firms to share knowledge while retaining the right to appropriate its commercial value (Dahlander and Gann, 2010; Teece, 1986; West, 2006). If knowledge can be protected by IPR, organizations also may transfer IPR to other organizations (e.g., licensing) or negotiate shared rights in a joint venture (Grandori and Soda, 1995).

Finally, the *characteristics of organizational actors* pertain to their ability and willingness to engage in knowledge transfer (Martin and Salomon, 2003; Mowery et al., 2002). With regard to the ability to learn from others, many studies establish the importance of absorptive capacity for effective knowledge transfer (Cohen and Levinthal, 1990; Mowery et al., 1996). With our focus on how and when organizations decide to engage in interorganizational knowledge transfer, we also address the willingness to engage in knowledge transfer, which involves the willingness to learn – the determination to acquire knowledge (Hamel, 1991; Simonin, 2004) – and the willingness to transfer to others (Inkpen and Tsang, 2005). Willingness to learn from others depends on the perceived knowledge characteristics of the source, including the strategic importance of that knowledge (Pérez-Nordtvedt et al., 2008;

Tsang, 2002). Willingness to transfer to others might be hampered by fear of inadvertent knowledge losses (Cassiman et al., 2009; Dahlander and Gann, 2010) or free-riding by others (Dyer and Nobeoka, 2000), leading managers to protect their organization's knowledge base (Henkel, 2006; Khanna et al., 1998; Norman, 2004). The willingness to transfer knowledge to others thus tends to be higher in relations characterized by trust and commitment (Dyer and Nobeoka, 2000; Inkpen and Tsang, 2005).

Although prior research clearly offers valuable insights into influences on the amount of interorganizational knowledge transfer, we lack sufficient understanding of how and why organizations might *change* their knowledge transfer activities (Dahlander and Gann, 2010; Easterby-Smith et al., 2008; Phelps et al., 2012). By focusing on existing knowledge alliances and their characteristics (e.g., Simonin, 2004; Tsang, 2002), most studies adopt a variance approach (Mohr, 1982; Van de Ven, 2007) and explain variance in the amount of knowledge transfer by variance in its antecedents. These antecedents are modeled as both necessary and sufficient causes, such that a change in the antecedent seemingly always prompts a change in the outcome (Mohr, 1982). Yet relational contexts and knowledge bases rarely can change quickly; it takes time to build relationships, accumulate tacit knowledge, and establish formal appropriability. These rather stable characteristics are unlikely to form the necessary and sufficient causes of more discontinuous changes in an organization's engagement in interorganizational knowledge transfer, because changes in the outcome are not always preceded by changes in the antecedents.

Also an actor's willingness to engage in knowledge transfer – associated with the actual decision to engage in knowledge transfer – thus far has been treated as a given antecedent (Simonin, 2004; Tsang, 2002) or explained by the relational context (Inkpen and Tsang, 2005) and knowledge characteristics (Pérez-Nordtvedt et al., 2008). Thus, willingness to engage cannot suffice to explain changes in knowledge transfer either. It is both theoretically and practically relevant to understand better why and when organizations engage in or actively block knowledge transfers, as well as the changes in these decisions over time.

In our quest to clarify the dynamics of knowledge transfer, it emerged from initial analysis that these changes relate to the framing of future developments of the innovation. The concept of framing is rooted in strategy and organizational literature that investigates how organizational actors process information and how the resulting interpretations mediate their actions (Daft and Weick, 1984; Kaplan, 2011; Walsh, 1995). Cognitive processes become particularly important when information is ambiguous or absent, such as in technological innovation processes with uncertain outcomes (Kaplan and Tripsas, 2008). The complexity and ambiguity of technical information challenges actors to develop cognitive structures (including frames) that transform a complex information environment into a tractable one (Walsh, 1995). These cognitive structures then allocate the actors' attention, guide their evaluations of ambiguous information, and provide a basis for inference. We attend to framing to address our research question regarding how and why organizational actors' decisions about interorganizational knowledge transfer change over time.

METHODS

We conducted a longitudinal study with qualitative procedures to develop theory about the dynamics of interorganizational knowledge transfer (Locke, 2001; Vaughan, 1992). Specifically, we sought to develop a theoretical explanation of decision making on interorganizational knowledge transfer activities. Because we aim to explain changes, we took a process approach focusing on how change is brought about by actors that are enabled and constrained by evolving structures (see Giddens, 1984). Therefore, we needed detailed data about motives and actions over time, as can best be collected from qualitative data sources such as interviews (Langley, 1999). Because a core objective was to explore and theorize about knowledge transfer dynamics, we also needed an open inquiry approach, which is enabled by qualitative methods (Strauss, 1987). Finally, with this qualitative research approach, we could tap multiple, complementary data sources and generate a comprehensive analysis of the knowledge transfer interactions (Eisenhardt and Graebner, 2007).

For our study context, we chose a network of organizations involved in the development of fiber metal laminates (FML), a material initially explored by the Dutch aircraft manufacturer Fokker in cooperation with Delft University of Technology (TU Delft) and the Dutch aerospace laboratory NLR. Fiber metal laminates are sheet materials, composed of thin layers of metal (here, aluminum) and fiber adhesives, which have been developed to reduce metal fatigue problems in aircraft. Researchers from TU Delft engaged with the Dutch chemical company Akzo for the supply of aramid fibers, 3M for the adhesive, and Alcoa for aluminum sheets. Over the years, other parties joined and withdrew, such as Bombardier, Boeing, McDonnell Douglas, and Saab (see Berends et al., 2011). Others became increasingly involved over time, such as Airbus and Stork Fokker; two firms that collaborated closely to develop the FML application "Glare" for the fuselage of the Airbus A380. This marked a significant innovation, as the introduction of new classes of materials in primary aircraft structures is rare (Vlot, 2001).

This setting is well suited to investigate interorganizational knowledge transfer dynamics. First, the interactions extended over three decades, of which we studied a period of more than 20 years related to the development of Glare (1987–2010). Second, extensive documentation was available, including historical accounts, patents, publications, and public sources, allowing us to triangulate our primary, interview-based data (Jick, 1979). Thus, in this setting, the phenomena of interest were present to a high degree, well documented, and extended over time (Pettigrew, 1990).

Data Collection

Data collection started with interviews of people who had central roles in the development of FML. A first contact at Stork Fokker (which produced Glare for the Airbus A380) provided initial information that helped us identify key informants, complemented by the documented history of Glare (Vlot, 2001). Subsequently, we used snowball sampling to identify other key informants, such that we asked interviewees to identify relevant informants and followed up with people mentioned in narratives, interviews, or documents. We also deliberately searched for organizations and informants that were no longer active, for instance due to individual retirement, organizational withdrawal, career moves, or conflicts. With these insights, we gathered accounts of less fruitful episodes and closed collaborations, which reduced the threat of self-promotion or overemphasis on past successes (Eisenhardt and Graebner, 2007).

The interviews took place over a five-year period. The initial round of 18 interviews occurred in 2005 and 2006 and resulted in the initial case history and analysis. Then between 2007 and 2010, we conducted 24 additional and follow-up interviews and engaged in multiple e-mail conversations pertaining to specific questions. Ultimately, we conducted 42 in-depth interviews with 30 actors who participated centrally in the development of FML. Many served in different organizations over time, so we had multiple interviewees per organization. The interviews were recorded and transcribed, and most of them were conducted by at least two researchers. These waves of interviews enabled us to follow developments in real time for five years of the innovation trajectory. We reconstructed developments before 2005 retrospectively by seeking data about each significant event from at least three respondents, who represented at least two organizations (see Eisenhardt and Graebner, 2007). Thus we could tap potential differences in perspectives and emotional involvement (Golden, 1992; Huber and Power, 1985).

The interview protocol started with questions about the interviewee's career history, involvement with FML, and the involvement of the organization. Then we focused on specific knowledge transfer interactions and asked about the initiation, change in, and possible termination of all interorganizational knowledge transfer interactions; the motives for particular actions; and how interviewees framed the future of FML at certain points in time. Follow-up interviews focused on the process as it had evolved since the initial interview and any changes in the framing. Subsequent interviews also offered information about issues that might have been confidential during the initial interviews.

We triangulated these interview data with other sources (Jick, 1979). First, we consulted a technical text about FML and narratives of its history, such as those by Vlot (2001), Vlot and Gunnink (2001), Vermeeren (2003), Vogelesang (2003), and Alderliesten (2009). Second, we collected archival documentation, such as technical publications, patents, theses, conference proceedings and participant lists, sales brochures, research program reports and documents, press announcements, newspaper articles, and public interviews. Table I summarizes our data sources and their uses in our analysis; Table II provides details about each participating organization and interviewee.

----- Insert Tables I and II about here -----

Data Analysis

The first step in our analysis, starting in 2005, was to create a comprehensive narrative of the FML history. We coded the interview transcripts for descriptions of actors, decisions and actions to generate an overview of chronological events (Langley, 1999), and mapped of the evolution of the collaborative network (see Berends et al., 2011). We sent the resulting initial narrative to 15 interviewees for feedback. Their comments established the reliability of our narrative, in that they suggested only a few minor modifications. The subsequent data collection extended this initial interpretation.

In the second analytical step, we identified knowledge transfer interactions. Specifically, we collected interview segments and other data sources that indicated that the involved organizations shared knowledge, bought or sold knowledge, invited other parties to share knowledge, stopped knowledge sharing or transfer interactions with other parties, or shielded and protected knowledge for others. These knowledge transfer interactions provide the units of analysis, embedded in the case of FML development.

Finally, we developed explanations for the observed interorganizational knowledge transfer dynamics. During multiple sessions we jointly interpreted and coded data to create shared understanding of ambiguous information, and we established a coding scheme, based initially on open coding of the data. We compared and analyzed knowledge transfer interactions with regard to the related knowledge transfer decisions and characteristics of the organizational actors, their relations, and their knowledge. By going back and forth between the raw data and existing theoretical concepts, such as from the literature on cognitive framing (e.g., Dutton and Jackson, 1987; Kaplan, 2011), we refined and reworded the observations and developed theoretical observations or second-order themes (Gioia et al., 2013). Organizing these theoretical observations into theoretical categories suggested explanations of changes in knowledge transfer interactions over time. Figure I depicts the data structure.

----- Insert Figure I -----

All analytical steps were executed iteratively during the entire data collection period, from 2005 to 2011, and jointly by all three authors, which produced a rich understanding of the FML history. Realizing that all interpretations are fallible and influenced by theoretical preconceptions, we discussed all differences of opinion and, if necessary, solicited input from interviewees until we reached consensus. Discussions throughout the data collection and analysis inhibited any tendencies to overidentify with particular interpretations and helped to reach intersubjective agreement.

FINDINGS

Key Elements of Interorganizational Knowledge Transfer Dynamics

In our study context, organizations repeatedly changed their knowledge transfer interactions with other organizations. The network of collaborating partners grew and shrunk over time, and knowledge transfer linkages repeatedly spanned continents, only to be severed again later. To explain interorganizational knowledge transfer dynamics, we rely on five theoretical categories: deciding about engagement in interorganizational knowledge transfer, (re)framing innovation, events triggering (re)framing, the developing knowledge base, and the evolving relational context (see Figure I).

Deciding about engagement in interorganizational knowledge transfer

Literature on open innovation suggests a distinction between pecuniary and non-pecuniary knowledge exchanges (Dahlander and Gann, 2010), but most empirical studies investigate only one form, such as pecuniary knowledge exchange in the form of licensing. We coded knowledge transfer decisions as two distinct but not exclusive categories: knowledge sharing and knowledge trading. Whereas knowledge sharing involves no direct monetary compensation, knowledge trading requires a market transaction. Both categories consisted of decisions to initiate or intensify sharing or trading, as well as to reduce or terminate it. As an example of knowledge sharing, Structural Laminates Company (SLC, a joint venture of Alcoa and Akzo) intensified this by deciding to send an engineer to Boeing to work on particular FML applications and share tacit design knowledge: “I visited Boeing quite frequently, and I started by being located for several months at Boeing” (SLC engineer, 25O). With regard to knowledge trading, we observed both the sale and the acquisition of knowledge. For example, when Alcoa backed out of the joint venture in 1997, Akzo’s strategic advisor decided to request a license for applications of FML in Europe:

> Krook [advisor of Akzo] said: but Airbus is interested in Glare. And he [the Alcoa representative] said: then Airbus can get a license. Krook said: then, Akzo can get a license as well. That’s how the license passed into Dutch hands again. (SLC manager 8T)

(Re)framing innovation

Framing the innovation development as an opportunity or threat influences the decision to initiate, intensify, reduce or terminate knowledge transfer activities toward a certain partner. Opportunity and threat categories are frames that decision makers use frequently to interpret strategic issues. Issues framed as opportunities appear beneficial and under the organization's control, whereas those framed as threats appear detrimental and beyond control (Dutton and Jackson, 1987; Kennedy and Fiss, 2009). Framing the innovation's future concerns both the creation and the appropriation of value, namely, as an opportunity for the organization to create and appropriate value or the threat that others might create or capture value. For example, Akzo and 3M managers framed the development of the first FML variant Arall (a predecessor of Glare) as an opportunity to create and appropriate commercial value: Akzo managers wanted new applications for Akzo's fibers, and 3M managers expected to sell large volumes of adhesives for new generations of aircraft (to "cover aircraft surfaces with multiple layers of adhesives" as a 3M sales representative [20M] phrased it). A TU Delft professor and his academic colleagues also framed this development as an opportunity to appropriate value in terms of reputation, funding, and educational activities:

> Maybe, I could have gained three million dollar, but I didn't like that at all. I wanted a good cooperation with the industry, enabling my students to develop the material. (Vogelesang, in the Dutch newspaper *de Volkskrant*, 2002)

Yet even when actors frame innovation developments as opportunities, they might simultaneously perceive threats that other actors will appropriate the resulting value. As an Airbus engineer explained:

> Look, the only thing that Airbus fears is their competitor, which is Boeing. Besides that, there is no competitor for Airbus. Which implies that they did not want Boeing to acquire their knowledge at the short term. (Airbus engineer 11A)

Opportunity and threat frames thus may coexist, though one usually dominates. We therefore distinguish three core frames for the future of the innovation process: framing as opportunity, framing as threat, and unframing as opportunity, such that the opportunity appears to shrink or vanish completely. We did not find any knowledge transfer decisions that suggested threat unframing, perhaps because unframing a threat does not result in an observable change in decisions about knowledge transfer interactions.

Unframing an opportunity relates to an actor's time horizon. For example, researchers from TU Delft, Alcoa, and Akzo imagined applying FML to commercial aircraft within about five years. The aircraft development programs that could incorporate FML offered rare windows of opportunity, so any cancellation or postponement of a program implied that the opportunity was suddenly distant or, for some parties, beyond their time horizon (see Das, 2004). In the 1990s for example, the opportunity to apply Glare to Boeing aircraft and the Saab 2000 disappeared, and the Fokker 130 program was cancelled. In such situations, industrial parties (i.e., 3M) backed out, because the opportunities to capture value moved beyond their time horizon.

Event triggering (re)framing

(Re)framing is triggered by three types of events, which can co-occur. First, company-*internal* factors, such as changes in company strategy, can lead to (re)framing. These company-internal factors have direct influences on the type of reframing, because the people who change the internal strategy have their own strategic agendas, with consequences for framing the innovation as an opportunity, threat, or unframing. In 1998, at Akzo, one of the early FML partners, managers decided to focus on paint and coatings and sell the fiber division. Thus, they lost their product/technology fit with FML, which led them to reframe FML development.

Second, *external* factors, such as changes in the wider market and industry environment, trigger (re)framing. The sources of these changes do not necessarily concur with the preferences of the decision makers so the type of (re)framing is typically not determined by the change itself but rather by the responses to it. At Alcoa, changes in the market and industry triggered multiple (re)framings, in terms of both opportunities and threats. When composites were introduced as an aircraft material, Alcoa managers framed FML as an aluminum-based material that still could compete with composites. But when aircraft manufacturers faced problems with applying composites, increasing the likelihood of a stable aluminum market, this triggered Alcoa managers to frame FML development as a threat to Alcoa's still successful full-aluminum products.

Third, the *endogenous* results of the knowledge transfer process itself, such as technological breakthroughs, trigger (re)framing. These triggers reflect the ongoing collaborative development, so they are path dependent. When joint research between TU Delft with the U.S. Air Force showed that Glare had promising properties as a repair patch installed over cracks in fuselages or wings of existing aircraft, TU Delft researchers began to frame the innovation as an opportunity to repair existing Hercules 130 or C-5 Galaxy aircraft. All three triggers help to understand why and when an actor's framing of the future, and thus its decision about involvement in transferring knowledge about FML, might change. These triggers not only prompt (re)framing the innovation development but also influence the type of reframing in terms of opportunities and threats.

The developing knowledge base

Characteristics of the developing knowledge base, such as formal appropriability and the accumulated stock of tacit knowledge, are *incorporated* in (re)framing and were *leveraged* in decisions about engaging in interorganizational knowledge transfer. A Bombardier manager incorporated Bombardier's accumulated stock of tacit knowledge in framing FML development as an opportunity for a new aircraft. Bombardier had all the required production equipment and the expertise to absorb FML knowledge, so it could produce FML for its own aircraft, which also provided an interesting knowledge exploitation opportunity:

> We do have those facilities both in terms of pretreatment and autoclaves …, that's part of the reason that we were interested in Glare, because it was based on metal bonding technology.… We've had a major investment in facilities. (Bombardier engineer 16B)

Actors also leveraged their evolving knowledge base for decisions about engaging in interorganizational knowledge transfer. When the appropriability of their knowledge was protected by IPR, organizations could share and trade knowledge while protecting the value created. Thus Akzo managers used their IPR over FML to share knowledge with other commercial parties, such as Alcoa and 3M, without worrying that Alcoa or 3M might appropriate too much value. In contrast, a lack of IPR constrained actors, making them hesitant to share their knowledge. They might instead opt for secrecy and avoid sharing knowledge, even in close collaborations. Noting the IPR struggles between Akzo and Alcoa, an Alcoa representative pointed out that without some form of appropriability, Alcoa would never engage in knowledge transfer:

> Alcoa did not want to pursue a concept or a business possibility without having control of the technology. (SLC manager 6L)

The evolving relational context

The focal knowledge transfer activities occur in networked, collaborative, ongoing innovation processes, in which multiple actors worked to develop and apply a new aircraft material. This evolving relational context, consisting of prior relationships and contractual governance mechanisms, was incorporated in (re)framing the innovation development. Specifically, actors developed frames that reflected how their prior ties and contractual governance mechanisms might apply in future collaborations. For example, in the cooperation between Airbus and Stork Fokker to apply Glare to the A380, FMLC, as a “center of excellence”, served to develop and spread Glare knowledge. But FMLC employees were constrained by their strong ties and contracts with Airbus and Stork Fokker, which feared that knowledge could leak “across the ocean” to Boeing (Vlot, 2001: 130). In an unforeseen and unintended reaction, individual FMLC researchers reframed the future and decided to counter the imposed constraints by starting a new company called GTM.

The relational context was also leveraged in decisions to engage in knowledge transfer. Prior relationships enabled actors to establish connections or reinvigorate dormant ties (see Gulati and Gargiulo, 1999) but also prevented others from sharing or trading knowledge. In 1987, Alcoa managers used their strong ties with McDonnell Douglas and other aircraft manufacturers to exchange knowledge about its FML product and thus develop applications for new aircraft:

> [Alcoa's FML director] had access to key people within the company and was very motivated. It was very unusual.… There is no doubt that MDC and Alcoa had a close relationship and that was reflected by the fact that we allowed these people to come into our company, basically from Alcoa. I never heard of anything like that happening for any other product. (MDC engineer 15D)

Moreover, contractual governance mechanisms enabled actors to force network partners to halt their knowledge sharing activities with others, such as potential competitors. Stork Fokker's role as one of the founding parties enabled it to restrict FMLC from sharing FML knowledge with others:

> FMLC intended to be an institute ... to market [FML] knowledge to Boeing and Bombardier and to reach out to others.… But [the knowledge] was always kept under a lid.… Sharing knowledge beyond the cooperation between Stork Fokker and Airbus was not possible. (NIVR manager 5N)

A Model of Knowledge Transfer Dynamics

In Figure II we reveal how the five elements together explain how and why decisions about interorganizational knowledge transfer change over time. The process model centers on the variable nature of cognitive framing as a primary source of changes in organizations' decisions to engage in interorganizational knowledge transfer activities. Framing and reframing of innovation developments are triggered by internal, external, and endogenous factors. The actor's (re)framing incorporates the developing knowledge base and evolving relational context, which subsequently get leveraged in the actor's decision to engage in interorganizational knowledge transfer activities. Eventually, knowledge transfer interactions also shape the knowledge base and the relational context – though these change at a relatively slow pace – when new knowledge gets accumulated and new relationships form. Because actors incorporate in their framing the existing relational context and knowledge base, the actor's framing is partly path dependent but not determined by knowledge or relationships. Only by including the effect of shifting frames can we understand how and why organizational actors decide to engage in or withdraw from knowledge transfer interactions.

---- Insert Figure II about here ----

When they frame the innovation development as an opportunity, organizational actors tend to initiate or intensify knowledge transfer activities. They leverage the evolving relational context to establish connections for knowledge sharing and joint knowledge development. Formal appropriability mechanisms lessen the hesitation to open up knowledge transfer activities with competitors. Further, the knowledge base influences whether an innovation gets framed as an opportunity (e.g., Bombardier's knowledge base suited FML production).

A threat frame instead dominates when opportunities for value appropriation appear to be moving closer in time, because actors imagine that others might capture the value from the innovation. When a threat frame becomes dominant, the general tendency is to protect any chances to appropriate value. Actors engage selectively in knowledge sharing interactions and close other knowledge flows; sometimes they even attempt to close knowledge flows between other actors in the network, particularly with (potential) competitors. In our observations, actors usually attempt to close their cooperation with direct competitors and enforce exclusivity in knowledge sharing with suppliers or customers, if they can. For an innovation framed as a threat, powerful actors leverage their relational context, and especially the presence of contractual governance mechanisms, to force others to halt knowledge sharing. The existing knowledge base – particularly accumulated tacit knowledge – thus invigorates the threat frame and enables actors to decide whether to protect knowledge, because transferring tacit knowledge requires dedicated investments.

Finally, when actors unframe the innovation development as an opportunity, they unilaterally reduce or terminate knowledge sharing and shift to knowledge trading. They leverage their relational characteristics to transfer or sell remaining activities or knowledge resources to others. Moreover, if they own IPR, actors leverage this resource to sell knowledge rights to others, through which they could appropriate at least some value from their past investments in innovation development and knowledge sharing.

To illustrate how this model explains the dynamics of interorganizational knowledge transfer over time, we narrate the changing involvement of three organizations. Overviews of the interactions we analyze for each organization appear in Tables III–V; a comprehensive view of the interactions all analyzed organizations is available on request.

----- Insert Table III, IV and V about here -----

Alcoa

Initially, researchers and managers at aluminum producer Alcoa framed the emerging FML technology as an aluminum-based answer to the development of black composites for aircraft structures, in particular for wings, and they invested in acquiring an exclusive license from Akzo and developing the technology. In 1987, when FML technology was ready for production, Alcoa managers opened a plant in Pittsburg (PA) to produce Arall and used their strong ties in the aircraft industry to share knowledge with aircraft manufacturers such as Boeing, Aérospatiale, and Lockheed to increase market interest in material (Table III, interaction 1). As a result, Alcoa entered into a contract with McDonnell Douglas to develop an Arall application for the cargo door of the C-17 military aircraft.

Unfortunately, TU Delft researchers found some detrimental properties of Arall. After innovating the glassfiber–based alternative Glare, they convinced Akzo's R&D managers to invest in Glare research, transferred the IPR to Akzo, and started to market Glare. Thus, the interorganizational knowledge transfer process resulted in a new material, but at Alcoa, this new innovation was framed as a threat to value appropriation from past investments in Arall. Furthermore, Alcoa did not have IPR over Glare. As an Akzo product developer stated:

> Alcoa set its heart on Arall, and they were not at all convinced about the superiority of the Glare product. Moreover, I think that Alcoa already put a lot of money into Arall, and they did not want to exchange Arall for Glare. (Akzo product developer 28Z)

Alcoa managers decided to resist knowledge sharing for Glare and pushed for knowledge sharing about Arall instead, using their strong ties in the industry (Table III, interaction 2).

In 1990, Boeing management selected Glare for the cargo floor of its 737. This event finally prompted Alcoa's managers to go along with Akzo and Glare and enter into a joint venture, Structural Laminates Company (SLC), which owned all IPR and coordinated technology development. Somewhat later, a change of leadership in the aerospace division (the new vice president came from Alcoa's core "sheet and plate" aluminum division) triggered another reframing of FML innovations as a cannibalizer in the fuselages market. Glare, unlike Arall, was particularly well suited for fuselages, such that FML got framed as a competitor to Alcoa's aluminum alloys:

> Our people were working on fuselages. For fuselages, Alcoa had a new [aluminum] material and fuselages are their core business. That generated a lot of money for them. And we were marketing fuselage material, which created a conflict with Alcoa. This finally resulted in: we will cut down SLC to a technology house, just to maintain the patent. (SLC manager 8T)

The new vice president demanded that SLC refrained from marketing fuselage applications, but this strategic shift never happened, with important consequences for interorganizational knowledge sharing (Table III, interaction 3). Alcoa managers leveraged their strong ties and existing contracts with Boeing and McDonnell Douglas to reduce collaboration on Glare. An SLC representative recalled:

> The more successful we were with Boeing, the more of a concern this became for the Alcoa group. It got to the point where ... the Alcoa sheet and plate sales people continued to interfere with our development efforts within OEMs like Boeing and Airbus. To the point where – with Boeing – we believed that they were actually giving bad information [to Boeing]. (SLC manager 6L)

In 1993, Boeing management finally called for a moratorium on Glare studies. Meanwhile, Alcoa still controlled the IPR for FML, through its majority share in SLC.

In 1997, external changes – Fokker filed for bankruptcy, and Saab and McDonnell Douglas lost their interest in FML – triggered Alcoa to unframe FML development as an opportunity and entirely halt its knowledge sharing (Table III, interaction 4). Considering its knowledge base, especially the existence of formal appropriability and IPR, Alcoa's reduced collaboration had a huge impact on knowledge transfer activities related to Glare and prevented others from appropriating the patented technology.

> We maintained the licensing and the patents and those kinds of things. There was interest in doing that: maintaining the technology. But we took a wait-and-see attitude. (Alcoa engineer 3L)

Nevertheless, Alcoa still leveraged the formal appropriability of its knowledge base and sought revenues from selling licenses for European applications to Akzo and for secondary structures (not fuselage skin or wings) to other companies.

Around 2005, the framing shifted to view FML development as an opportunity again. Triggered by external changes in the market and the technology, including the major FML application on the Airbus A380 and Boeing's full-composite 787, Alcoa's management revived framing FML as an opportunity to counter composites (Table III, interaction 5):

> There is a program within Alcoa that is funded towards fiber metal laminates. It has basically come full circle. It's back to where it was in 1982. (Aviation Equipment representative 6L)

Alcoa started a collaboration with GTM, a company consisting of former SLC, FMLC, and TU Delft researchers. The opportunity frame also was enabled by the informal ties that Alcoa employees maintained with the researchers and the IPR that Alcoa still owned; both the relational context and the knowledge base could be leveraged in the decision to reengage. Through combined efforts by GTM and Alcoa, erstwhile partners returned to cocreating FML, including Bombardier, the U.S. Air Force, and Boeing. GTM and Alcoa engineers jointly developed multiple FML variants, which triggered Alcoa managers to frame a threat of competitors appropriating some created value (Table III, interaction 6). Therefore they reduced and restricted knowledge sharing, protecting their knowledge with five patents in 2005 and 2006, as enabled by contractual agreements between Alcoa and GTM.

Three years later, Alcoa's product managers once more reframed FML in general as a threat to their aluminum business and halted their collaboration yet again (Table III, interaction 7). This reframing was triggered by internal strategy changes and problems that Alcoa's clients encountered in developing aircraft with materials other than aluminum (FML and composites). Alcoa's management decided to stop the joint knowledge sharing program, but because they still framed FML as a dormant threat to their aluminum products, they retained the patents and granted no licenses for Glare applications on primary aircraft structures in the United States:

> Alcoa still has total control of the patents. There is one person within Alcoa that basically has that responsibility. He is the vice president of aerospace sheet and plate products. The licenses here in the US [for secondary applications] were sold to … Aviation Equipment. (Aviation Equipment representative 6L)

----- Insert Table IV about here -----

Bombardier

Our model also explains changes in the involvement of more peripheral players, such as Bombardier. At the first FML conference in 1987, de Havilland, one of the companies that would later make up Bombardier, participated, though this involvement remained informal, because there was no new aircraft program available for FML applications. But by 1996, the development of the new Learjet 45 triggered Bombardier engineers to frame FML development as an opportunity for a specific part of the aircraft, incorporating existing relationships with the FML community and their knowledge about metal bonding (Table IV, interaction 1). They started sharing and codeveloping knowledge about this particular application, in which setting they leveraged their existing ties as well as their knowledge base.

After the application of FML on the Airbus A380, Bombardier began developing a new aircraft, the C-series. Triggered by their good experiences with Glare, Bombardier engineers framed the innovation as a new opportunity, incorporating in their framing their existing knowledge base and production capacity (see our previous discussion), and existing relations within the FML community (Table IV, interaction 2). Therefore, Bombardier managers started negotiating with Stork Fokker about knowledge sharing and a license to produce and apply Glare. Yet Bombardier's engagement interacted with Stork Fokker's threat framing, which motivated it to block knowledge transfer with Bombardier. As a manager from Stork Fokker reported:

> There certainly was demand [from Bombardier], but first of all, the exclusivity agreement with Airbus held us back, and second, some of those who asked [for Glare] laid down conditions we simply could not agree to. Our idea was not that we would tell them how to produce Glare and then never hear from them again. (Stork Fokker manager 2F)

Stork Fokker's management remained unwilling to sell Bombardier production rights:

> One of the benefits to be accrued from Glare is the splicing technology. And if you begin to do that you begin to infringe people's patents and so on. And it was difficult to see through all of that. So the fact that we could just use the material [and not produce it], and [our] people and facilities were redundant, meant that we decided to change to aluminum. (Bombardier engineer 16B)

As a result, the cooperation between Bombardier and Stork Fokker broke down. This illustrates how the different frames of (potential) collaborators resulted in changes in interorganizational collaboration and knowledge transfers over time.

----- Insert Table V about here -----

Airbus

In 1988, researchers at MBB (which later became part of Airbus, together with Aérospatiale) learned about FML, which triggered an opportunity frame for a new generation of aircraft (Table V, interaction 1). Their existing knowledge base enabled them to grasp the essence of the material, and they contacted TU Delft researchers. Intensive cooperation during the test program established a basis for continued knowledge sharing, which also was facilitated by strong personal ties between MBB and TU Delft engineers. Persistent knowledge sharing in SLC also helped convince some of the involved parties to continue to frame Glare as an opportunity. German and French Airbus partners became increasingly involved in jointly designing and testing Glare for new aircraft.

Building on their existing contacts at Aérospatiale, SLC engineers initiated a joint research program with multiple partners from the aircraft industry by sending SLC engineers to Aérospatiale in Toulouse. Aérospatiale's managers agreed but also framed the innovation development as a threat, because it included competitors that could appropriate value (Table V, interaction 2). Therefore, they leveraged their relation with SLC and TU Delft to enforce restricted knowledge sharing:

> We got much information from Aérospatiale ... and we would distribute the knowledge among customers.... But Aérospatiale was afraid of distributing knowledge.… We signed a nondisclosure with Aérospatiale, stating that we would do nothing with that information. (SLC engineer 27S)

When the results of the tests showed promising results, Airbus began to frame FML as an opportunity to solve some of the challenges that its proposed superjumbo faced (Table V, interaction 3). As an Airbus vice president noted,

> If we apply Glare on the A3XX, this will give a 15 to 20 ton weight reduction. (Dutch newspaper *NRC Handelsblad,* 1998)

Therefore, knowledge sharing intensified, and Akzo, TU Delft, and Stork Fokker employees were invited to work closely with the Large Aircraft Division of Airbus, enabled by their strong ties. Airbus's engineers and managers became more interested in applying Glare to the A380 superjumbo, but Alcoa was no longer backing the development of FML. Alcoa's management thus broke up the joint venture; Akzo negotiated a license for European FML applications. Therefore, Airbus managers could frame FML applications as an opportunity to create *and* appropriate value, because they could use this exclusive license. At the same time, the development of a production-ready FML was framed as a threat, due to the fear that competitors (i.e., Boeing) might walk away with the results (Table V, interaction 4):

> Airbus feared any flow of knowledge across the ocean.… The technology for Glare applications had to be guarded.… Airbus' nightmare scenario was that its precious new knowledge would fall into the hands of Boeing. (Vlot, 2001: 131)

By leveraging its strong ties and formal contracts with the involved parties, Airbus limited the sharing of knowledge with these parties – and limited it even more with others. When Airbus and Stork Fokker managers later signed an agreement to produce and apply Glare on the A380, this threat frame reappeared (Table V, interaction 5), such that Airbus managers even demanded exclusivity from parties related to Stork Fokker. That is, the contractual agreement with Stork Fokker was leveraged to block knowledge sharing, using Stork Fokker's role in FMLC.

DISCUSSION

We have addressed how and why organizational actors' decisions about interorganizational knowledge transfer change over time. We analyzed data related to more than two decades of technology development to identify how and why organizational actors change their engagement in interorganizational knowledge transfer in a network of organizations. From this analysis, we derived a cognitive framing model which offers an integrated explanation of the decisions to engage or disengage in knowledge transfer activities.

First, our cognitive framing perspective explains *discontinuous* changes in collaborative knowledge transfer activities, highlighting the role of the future in explaining such dynamics. While we know that organizational actors usually enter into knowledge transfer interactions for strategic reasons (Meier, 2011), which are typically future oriented (Das, 2004), most research has taken the actor's willingness to engage in knowledge transfer for granted and centers on antecedents that characterize the situation as it *currently* stands (e.g., relational context, knowledge base). The focus on antecedents of the current situation could explain continuous change (i.e., changes in knowledge transfer are explained by changes in these existing antecedents) but not discontinuous change. Less attention focuses on the actor's future-oriented agency (Phelps et al., 2012), except for the "shadow of the future," that is, the potential for future retaliation in response to opportunistic behavior (Heide and Miner, 1992).

Our study shows that discontinuous changes in knowledge transfer can be explained by (un)framing the innovation as an opportunity or threat, reflecting dominant frames in managerial cognition (Dutton and Jackson, 1987; Kennedy and Fiss, 2009). Despite the fact that these frames concern innovation developments that are far in the future – and not short-term expectations about costs and benefits – the framing appears variable, reflecting the uncertain fate of collaborative innovation. Though years of investment may be needed to create and appropriate expected value, unforeseen events can prompt actors to quite abruptly reframe future developments as opportunities or threats. Recall for instance how, triggered by internal strategy changes, Alcoa's management changed all of a sudden its framing of the FML technology from an opportunity to a threat framing, resulting in a reduction of knowledge transfer activities. This change could not be explained by just considering the knowledge base and relational characteristics, as they only gradually evolved, but we can understand why Alcoa's behavior changed by taking into account the framing of the future.

Second, our findings suggest a different theoretical role for characteristics of the relational context and knowledge base than usually assumed in existing studies. Many studies consider the relational context and the knowledge base as necessary and sufficient conditions for enhancing knowledge transfer in a given context (see Mohr, 1982). High quality relationships and good governance practices enhance knowledge sharing in established collaborations and enable engaging in new interorganizational knowledge transfer interactions (e.g., Becerra et al., 2008; Bygrave, 2007; Van Wijk et al., 2008). Moreover, a knowledge base consisting of established intellectual property rights and tacit knowledge is considered as an important condition for knowledge transfer (e.g., Dahlander and Gann, 2010; Grandori and Soda, 1995). Yet, our process study suggests that having the right relational context and knowledge base is not a necessary and sufficient condition that explains why organizations engage in knowledge transfer, but that their roles depend on how organizational actors incorporate them in their framing of the innovation. That is, changes in knowledge transfer cannot be explained by changes in characteristics but by how these characteristics get exploited through human agency. This exemplifies a dynamic interaction of structure and agency, in which structures enable and constrain actors but do not determine their behavior, as also proposed by structuration theory (Giddens, 1984). Organizational actors draw on the relational context and their knowledge base, without being determined by them; they exploit them differently in response to changes in framing opportunities and threats. Moreover, though difficult and not observed in our study, actors might pursue an opportunity even if they cannot leverage the right knowledge base and relational context (see Stevenson and Gumpert, 1985). As a result, there is not always a straightforward relationship between the firm's ownership of particular resources and the decisions about collaborative innovation (see Toh and Polidoro, in press).

Along these lines, we also identify salient differences in how organizational actors draw on their relational context and knowledge base. If the future is framed as an opportunity, existing relationships can be leveraged to initiate knowledge sharing. However, when future developments are framed as threats, existing relationships and contractual governance mechanisms can be leveraged to block knowledge sharing by others. This hindrance adds on to the constraining, lock-in effect of existing relations (Uzzi, 1997); we show that such lock-in effects even can be exploited purposefully by others. With this insight, we can also partially explain conflicting research findings regarding the role of strong ties (Phelps et al., 2012), which might be instrumental to knowledge sharing or serve as levers to limit a partner's ability to reach out to new and diverse partners. If the innovation development gets unframed as an opportunity and knowledge sharing ends, social ties may exist, dormant, to be leveraged later for a new opportunity (see Berends et al., 2011; Levin et al., 2011). Similarly, actors incorporate the developing knowledge base in framing opportunities according to existing knowledge and property rights. In knowledge transfer decisions, actors leverage this knowledge base to either trade knowledge or prevent others from applying that knowledge.

Third, our findings also extend cognitive framing theory. Not only have we demonstrated the relevance of the threat and opportunity frames in a new context, but we also have identified unframing as influential. Most studies assume opportunity framing as a driver of the decision to engage in interorganizational collaboration (Mariotti and Delbridge, 2012; Tyler and Steensma, 1998) and others have included threat framing as the contrasting dominant frame (Dutton and Jackson, 1987; Kennedy and Fiss, 2009). Dutton and Jackson (1987) argued that information that is congruent with the category used to frame an issue is more likely to be attended to and recalled, and ambiguous information is interpreted so as to conform to the expectations associated with a category; subsequently, organizational decisions are impacted by these categorizations. Unframing, or deframing, has attracted limited attention thus far (Dunbar et al., 1996), but our study shows that the disappearance of an opportunity frame also motivates organizational actors. Unframing leads to different knowledge transfer interactions than do opportunity or threat frames, so it is an important category to consider in further cognitive framing research. While framing processes direct the interpretation of new information to make it fit within existing expectations, our study shows that unframing is associated with a loss of expectations; actors subsequently just want to make the best of what they have. When actors unframe an opportunity, they appear to end knowledge sharing and shift to knowledge trading if they have IPR, and leverage their relational characteristics to transfer or sell remaining activities or knowledge resources.

This study offers important implications for managers of organizations that participate in an alliance or network to develop a technological innovation. For such an innovation to succeed, all partners that own crucial knowledge must remain open to knowledge transfer (Powell et al., 1996; Van Wijk et al., 2008), unless a replacement provider of similar knowledge can easily be found. We also observe rather sudden discontinuities in actors' openness to knowledge transfer. To make predictions about an actor's future openness, it is necessary to know how that actor frames the future and on which knowledge bases and relational contexts the actor draws. Organizations with vested interests in collaborative innovation should consider explicitly how they frame the future and how triggering events might affect their own framing, as well as that of others in the network – particularly of partners that can influence the frames and/or behaviors of other network partners through their strong ties. Our advice to managers therefore is to regularly put themselves in the shoes of their alliance partners, imagine how they may frame the future, and influence that framing when necessary.

Limitations and Boundary Conditions

Several limitations of this study require consideration. For only part of the 20-year time span could we ask interviewees about their framing of the future; for the first 15 years, we had to rely on the interviewees' retrospective reconstruction of events and the frames they used at that time. Although this restriction may limit the accuracy and completeness of our interview data, we also were able to use published accounts of events and expectations, written at various times prior to 2005. Our rich, varied data sources enabled us to triangulate across multiple fallible perspectives. With this research design, we also identified important long-term dynamics, which would be hard to observe in a real-time study of limited duration.

Because we studied the innovation process related to one specific class of materials, a key question is whether our findings are idiosyncratic to FML or the aircraft sector, or if our insights from this case might explain knowledge transfers in other contexts too. In this sense, we consider some boundary conditions on the applicability of our findings. First, these findings emerge in an innovation context, which implies uncertain future developments and thus invokes framing of the future. The opportunity and threat frames we found even related directly to innovation developments. Innovation processes are marked by a distant, variable time horizon, during which time an innovation process can get delayed, or firm and industry changes might trigger the unframing of the development as an opportunity. In other contexts, opportunity and threat frames may be less dominant in expectations of the future than, for example, change versus stability frames (see Sonenshein, 2010). Second, the organizations involved in FML development were part of a single industry, which is relatively common for collaborative innovation. Thus the involved organizations mostly had some background in aeronautical engineering, which formed absorptive capacity and actors incorporated this in framing potential competitive threats. If the actors represent different industrial contexts, the threat frame may be less relevant. These reflections go beyond our immediate evidence, which suggests the need to substantiate them in further research.

Conclusion

Our model offers provisional descriptions and accounts of phenomena that are open to revision and reformulation, but our analysis suggests that framing the future of a collaborative innovation process can effectively explain an organization's engagement in interorganizational knowledge transfer activities. That is, actors' framing of the future motivates how they leverage their relational context and knowledge base. Unlike the rather stable relational context or knowledge base, framing is variable and thus serves to explain discontinuities or unexpected changes in knowledge transfer interactions. If managers want to anticipate the actions and reactions of their collaborations, they should determine how those partners frame the collaborative innovation processes in terms of opportunities and/or threats.

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TABLE I

Data Sources

Source of Data	Type of Data	Use in the Analysis
Interviews	42 interviews executed with people who participated in the development of FML, including inventors, people from all involved organizations, and people only peripherally or no longer involved.	Gather data regarding the development of the knowledge transfer interactions, the actors' cognitive framing of the innovation, and the relational context and knowledge base.
	First round: 18 interviews, executed between September 2005 and May 2006, with 17 individuals (one interviewed twice). Recorded and transcribed, for a total of 297 pages.	Construct an initial case history of knowledge transfer events to identify patterns in those events.
	Second round: 23 interviews, executed between April 2007 and August 2008 with 13 new informants and 10 follow-up interviews. One key informant was interviewed again in 2010. Recorded and transcribed, for a total of 229 pages.	Trace developments in real time and verify details of the emerging analysis.
History Narratives	Books (3), articles, and reports (8) narrating the development of FML.	Construct an initial case history; gather information on events, relational and knowledge characteristics; provide clues of cognitive framing; give detailed documentation of the early years (e.g., Vlot, 2001).
Press Articles	Newspaper and industry journal articles from international and Dutch publishers: 166.	Triangulate data on events, relational context, and knowledge base; gather evidence of cognitive framing.
Internal Documents	Internal company documents such as product leaflets, presentations, press announcements, and reports, collected from websites, libraries, and the archives of informants: 43.	Triangulate data on events, relational context, and knowledge base; provide clues of cognitive framing.
Academic Publications and Patents	Academic (technical) publications by involved researchers, covering the analysis period: 185.	Triangulate data on relational context and knowledge base.
	Patents on FML inventions, covering the analysis period: 43.	Triangulate data on relational context and knowledge base.

TABLE II
Roles of Involved Interviewees and Organizations

Involved Organization	Interviewee Position(s) (ID)	Role in the Development of FML
3M (1981–1995)	Sales Manager (20M)	Supplying adhesive and prepregs, funding joint research and sharing knowledge about 3M adhesives and prepregs.
Aerohybrids (2009–)	President (6L; 3 interviews) Sales Manager (8T; 2 interviews)	Joint venture of GTM and Werco Manufacturing. Producing Glare and developing new Glare variants in cooperation with GTM.
Airbus (including Aérospatiale, MBB and DASA) (1988–)	Program Director A380 (9A) Designer (11A)	Performing joint FML studies for various applications, especially the A380. Once Glare was selected for the A380, also heavily involved in developing production knowledge with FMLC, Stork Fokker, and TU Delft.
Akzo (1981–1999)	Advisor (13Z) Development Engineer (17T) Sales Manager (28Z)	Funding FML development at TU Delft and NLR, supplying fibers and fiber knowledge, setting up internal Glare R&D department, patenting FML, and participating in SLC.
Alcoa (1981–1995; 2004–2010)	Program Director (9A) Technical Director (3L; 2 interviews)	Funding FML development at TU Delft and GTM, supplying aluminum and aluminum knowledge, production of Arall using Akzo's license, marketing and sales of Arall, participating in SLC.
Aviation Equipment (1995–)	Commercial Director (6L; 3 interviews)	Production of Glare for several secondary applications, using SLC/Alcoa's license and knowledge from (former) SLC employees.
Boeing (including de Havilland) (1991–1995)	Development Engineer (12B; 2 interviews) Development Engineer (25O; 2 interviews)	Preparing application of Glare on 777 and Dash-8, in close cooperation with TU Delft and SLC.
Bombardier (including de Havilland and Shorts) (1996–2005)	Development Engineer (12B; 2 interviews) Technical Director (16B; 2 interviews)	Performing joint FML studies, application on Learjet 45, preparing application on the C-series aircraft with Stork Fokker.
Delft University of Technology (TU Delft) (1978–)	Dean (5N) Assistant Professor (19T) Associate Professor (8T; 2 interviews) Professor (29T; 3 interviews) Professor (18T)	Fundamental materials research, research and development, testing FML, training new engineers and providing knowledge to other partners.
DFVLR (1987)	Development Engineer (14T)	Joint research and testing of FML (with TU Delft and Alcoa).
FMLC (2001–)	CEO (8T; 2 interviews) Development Engineer (17T) Development Engineer (23F)	Coordinating joint testing activities and acquiring government funding to perform FML studies.
Fokker/Stork Fokker (1978–)	R&D Manager (26F; 2 interviews) Aerospace Director (4F) Chief Engineer (10R) Designer (11A) Sales Director (13Z) Development Engineer (23F) Production Manager (24F) Development Manager (27S; 2 interviews) R&D Manager (2F)	Multiple joint development and testing activities, preparing application on Fokker 50 with TU Delft, production of Glare (with Airbus).

Involved Organization	Interviewee Position(s) (ID)	Role in the Development of FML
	Program Manager (30F; 2 interviews) Program Manager (27S; 2 interviews)	
Garuda Airlines (1994–1997)	Maintenance Manager (21G)	Glare studies with TU Delft and SLC; joint applications on DC-10.
Global Technics (2005–)	Commercial Director (30F; 2 interviews) Technical Director (11A)	Design, development and engineering of Glare in cooperation with Airbus; providing design knowledge.
GTM (2004–)	CEO (8T; 2 interviews) Technical Director (17T)	Development and testing of Glare in cooperation with Alcoa, TU Delft, and Airbus; providing material and development knowledge.
McDonnell Douglas (1988–1995)	Program Manager (15D)	Jointly testing of a Glare application on the C130 (with SLC).
NIVR (Netherlands Agency for Aerospace Programs) (1983–)	Project manager (1N; 2 interviews) CEO (5N)	Funding Dutch R&D on FML, no knowledge transfer.
NLR (Dutch aerospace laboratory) (1978–)	General Director (1OR) Test Engineer (22R)	Testing and certification of FML products, in cooperation with Fokker, TU Delft, SLC, and Airbus, providing testing knowledge.
SLC (later SLI) (1991–1997)	CEO (6L; 3 interviews) Technical Director (8T; 2 interviews) Board Member (13Z) Development Engineer (17T) Development Engineer (23F) Development Engineer (25O; 2 interviews) Sales Representative (28Z)	Joint venture Akzo and Alcoa, developing, testing, applying, and marketing Glare and Arall, in cooperation with almost all FML network partners.
U.S. Air Force (1995–)	Researcher (7U)	Retro-fit Glare applications on C130 and study applications on other aircraft in cooperation with TU Delft, SLC, Alcoa, and GTM.
Werco Manufacturing (2009-)	Business Developer (6L; 3 interviews)	Develop, produce, and market FML products in cooperation with GTM.

Note: Multiple interviewees worked simultaneously or successively for more than one company in the FML network.

FIGURE I
Data Structure

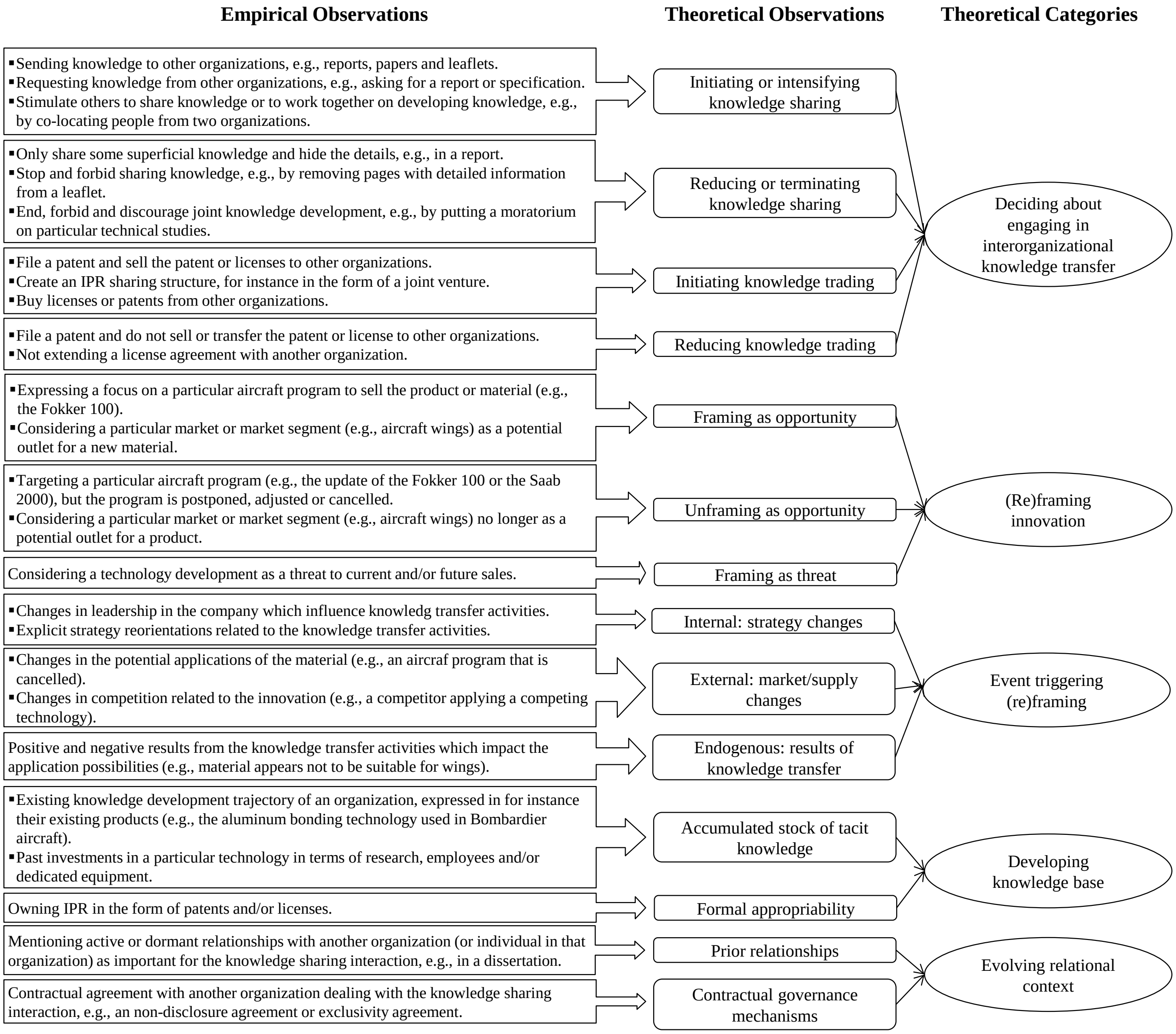

TABLE III
Analyzed Knowledge Transfer Interactions of Alcoa

Interaction	Event Triggering (Re)Framing	(Re)Framing Innovation	Deciding About Engaging in Interorganizational Knowledge Transfer	Evolving Relational Context	Developing Knowledge Base
1	*Endogenous:* The FML technology is ready for first application on real aircraft prototypes.	*Opportunity:* Alcoa managers frame an opportunity to create monetary value by applications of FML on wings for existing relationships.	*Initiate sharing:* Alcoa managers start sharing knowledge to potential customers such as MDC, Boeing, Aérospatiale, and Bombardier and hosts a conference to convince them about FML.	*Prior relationships:* Existing relationships and Alcoa's reputation as a major aluminum supplier help interest current customers in this new technology.	*Formal appropriability and stock of tacit knowledge:* Alcoa's exclusive license on Arall and unique tacit production knowledge reduce risks of sharing knowledge with customers.
2	*Endogenous:* Akzo/TU Delft's actions to convince the aircraft community about Glare, reduces the status of Arall and conflicts with Alcoa's aims.	*Threat:* Alcoa managers perceive the actions of Akzo and TU Delft as a threat.	*Reduce sharing:* Alcoa managers resist knowledge sharing with customers around Glare.	*Prior relationships:* Alcoa's strong commercial network in the aircraft industry enables it to continue with the 'old' Arall technology.	*Lack of formal appropriability:* Alcoa does not have a license on Glare technology and thus is not able to protect value appropriation.
3	*Internal strategy change:* Alcoa appoints a new vice president to the aerospace division, from its profitable sheets and plate aluminum division, who emphasizes existing profitable products over new technology development.	*Threat:* Alcoa managers perceive Glare to be a threat to the creation and appropriation of monetary value from aluminum with existing customers.	*Reduce sharing (and force others to do so):* Alcoa managers wind down its knowledge sharing with Boeing and MDC through SLC and asks Boeing to stop working on FML.	*Prior relationships and contractual governance mechanisms:* Long-standing relationships and existing contracts of Alcoa and Boeing with MDC enable Alcoa to influence the behaviors of Boeing and MDC.	*Formal appropriability:* Through its majority ownership of SLC, Alcoa controls FML IPR.
4	*External market changes:* Fokker files for bankruptcy, and Saab and McDonnell Douglas lose interest in FML.	*Unframing opportunity:* The opportunity of an application on a Fokker aircraft disappears. Alcoa managers unframe an opportunity to create value from further FML development.	*Terminate sharing, initiate trading:* Alcoa managers stop investing in FML and ends collaboration with Akzo. Alcoa keeps the patents and sells licenses for European and secondary applications to Akzo and Aviation Equipment.		*Formal appropriability:* Alcoa owns a majority of SLC and is also majority owner of the patents.
5	*External market change:* Airbus selects Glare for the A380 and Boeing decides to develop a full-composite aircraft (the 787).	*Opportunity:* Alcoa managers frame a renewed opportunity to create value from FML, as competitor of composites.	*Initiate sharing:* Alcoa managers invite FMLC and former Airbus employees to share and co-develop FML variants.	*Prior relationships:* Individual Alcoa employees have maintained their relationships with FMLC employees.	*Formal appropriability:* Alcoa still owns FML patents.
6	*Endogenous:* Alcoa and GTM cooperate on FML.	*Threat:* Alcoa managers frame a threat that competitors could benefit from the new FML technology they are developing.	*Reduce sharing:* Alcoa managers protect the outcomes of collaboration between GTM and Alcoa through trade secrets and shared patents; this knowledge is not traded.	*Prior relationships and contractual governance mechanisms:* Alcoa and GTM agree on tight and exclusive cooperation, which hides the results of the joint developments from the outside world.	*Formal appropriability:* Alcoa files new FML patents with GTM, which enable it to appropriate the value from the innovation development.
7	*Internal strategy change:* Alcoa's management decides that FML does not fit the business. *External market change:* The development of the Boeing 787 and Airbus A380 show problems with the new materials, and thus a reduced threat for aluminum.	*Threat:* Alcoa managers no longer frame FML as an opportunity but as a threat to value creation from aluminum.	*Terminate sharing:* Alcoa managers end joint program with GTM and other interested parties and blocks primary FML applications in the US.		*Formal appropriability:* Alcoa owns fundamental FML patents and can block primary FML applications in the US.

TABLE IV
Analyzed Knowledge Transfer Interactions of Bombardier

Interaction	Event Triggering (Re)Framing	(Re)Framing Innovation	Deciding About Engaging in Interorganizational Knowledge Transfer	Evolving Relational Context	Developing Knowledge Base
1	*External:* The positive Glare results awake interest at Bombardier. *Internal:* A new aircraft program is under development.	*Opportunity:* Bombardier engineers frame an opportunity to create value using Glare in its aircraft (e.g., Learjet 45).	*Initiate sharing:* Bombardier and SLC start co-developing applications for Bombardier aircraft.	*Prior relationships:* Bombardier and SLC employees have cooperated before.	*Stock of tacit knowledge*: Glare fits Bombardier's history with bonded aluminum.
2	*Endogenous:* Glare production technology is successfully applied on the Learjet 45. *Internal:* A new aircraft program is started.	*Opportunity:* Bombardier engineers frame an opportunity to create value from applying Glare on its new C-series aircraft.	*Initiate sharing:* Bombardier managers re-start knowledge sharing with FMLC.	*Prior relationships:* Bombardier employees have cooperated with FMLC employees in the past.	*Stock of tacit knowledge*: FML would nicely fit Bombardier's production capabilities.

TABLE V
Analyzed Knowledge Transfer Interactions of Airbus

Interaction	Event Triggering (Re)Framing	(Re)Framing Innovation	Deciding About Engaging in Interorganizational Knowledge Transfer	Evolving Relational Context	Developing Knowledge Base
1	*External:* MBB researchers learn about the FML technology, which is ready for first application on real aircraft prototypes.	*Opportunity:* MBB researchers frame an opportunity to apply FML on a new generation of aircraft.	*Initiate sharing:* MBB engineers contact TU Delft researchers.		*Stock of tacit knowledge:* The MBB engineers have some knowledge of the new materials.
2	*Endogenous:* SLC engineers intensify knowledge sharing with Aérospatiale.	*Threat:* Aérospatiale managers frame a threat of competitors appropriating value from this FML development.	*Reduce sharing:* Aérospatiale managers forbid SLC from disclosing the results of the cooperative innovation activities via an NDA.	*Prior relationships:* Aérospatiale employees had prior interactions and ongoing cooperation with TU Delft and SLC, and these parties want to continue.	
3	*Endogenous:* Airbus is involved in the development and testing of Glare.	*Opportunity:* Akzo, TU Delft, Stork Fokker, and Airbus employees frame opportunities to create value using Glare on the Airbus A3XX, backed by public funding.	*Intensify sharing:* Akzo, TU Delft, Stork Fokker, and Airbus employees increase knowledge sharing to further develop and test the envisaged parts and develop production knowledge.	*Prior relationships:* TU Delft, Akzo, and Stork Fokker have strong relationships with Airbus, which make good cooperation possible.	*Formal appropriability:* Akzo owns a license for European applications of Glare, which also enables Airbus to use and exploit the FML technology.
4	*Endogenous:* Airbus, Akzo, Stork Fokker, and TU Delft engage in intensive knowledge sharing.	*Threat:* Airbus managers perceive a threat that competitors (i.e., Boeing) will appropriate value from the unique FML material if knowledge leaks to those competitors.	*Reduce sharing:* Airbus managers restrict sharing knowledge with other parties by only sharing generic results and no details; in the cooperation, exact details are not disclosed to all parties.		
5	*Endogenous:* Airbus and Stork Fokker sign a cooperation agreement.	*Threat:* Airbus managers perceives competitors like Boeing attaining knowledge about Glare as a threat to value appropriation.	*Reduce sharing:* Airbus managers block knowledge sharing to parties outside the direct cooperation, such as by contractual agreements.	*Contractual governance mechanisms:* Airbus managers signed contracts with the involved parties like Stork Fokker.	

FIGURE II
A Model Explaining Dynamics of Interorganizational Knowledge Transfer Interactions