University of Groningen

To Complete a Puzzle, You Need to Put the Right Pieces in the Right Place

Kok, Holmer Jan

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2018

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Kok, H. J. (2018). *To Complete a Puzzle, You Need to Put the Right Pieces in the Right Place: Exploring Knowledge Recombination and the Creation of New Inventions*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen, SOM research school.

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 20-04-2024

Chapter 1. General Introduction

"Combinatory play seems to be the essential feature in productive thought" - Albert Einstein

Knowledge recombination is considered a main engine of technological growth (Carnabuci & Bruggeman, 2009; Schumpeter, 1934; Weitzman, 1998). In this process, new inventions originate from recombining existing knowledge components or reconfiguring existing combinations of components (Fleming, 2001; Galunic & Rodan, 1998; Henderson & Clark, 1990). Numerous important inventions originated from knowledge recombination, such as Ford's mass production techniques (Hargadon, 2002), Hewlett-Packard's inkjet printing technology (Fleming, 2002), the first amplifier circuit (Arthur & Polak, 2006), valuable polymers at 3M (Boh, Evaristo, & Ouderkirk, 2014), highly-efficient fuel cell systems (Sharaf & Orhan, 2014), and many more. The notion that every new technology, product or idea emerges from knowledge recombination processes is conceptually and empirically useful: it provides us with a framework to understand when and how valuable new inventions are generated. It is also inherently intriguing since it implies that most inputs and tools to generate new inventions are already available, they just need to be used in the right way.

Knowledge recombination plays a central role in the conceptual and/or empirical framework of seminal studies in different fields. At the firm-level, scholars rely on knowledge recombination to examine the benefits of different extramural knowledge sourcing strategies (Savino, Petruzzelli, & Albino, 2017; Van de Vrande, 2013). Indeed, scholars argue that foreign market presence (e.g. Berry, 2014; Kafouros, Buckley, & Clegg, 2012; Singh, 2008), entry into new technological domains (e.g. Furr & Snow, 2014; George, Kotha, & Zheng, 2008; Kotha, Zheng, & George, 2011), strategic alliances (e.g. Davis & Eisenhardt, 2011; Lahiri & Narayanan, 2013; Phelps, 2010), mergers and acquisitions (e.g. Ahuja & Katila, 2001; Makri, Hitt, & Lane, 2010; Valentini, 2012), corporate venture capital investments (e.g. Wadhwa & Kotha, 2006; Wadhwa, Phelps, & Kotha, 2016), and employee mobility (e.g. Tzabbar, 2009) provide access to novel complementary component knowledge, creating opportunities for valuable knowledge recombination (Fleming, 2002). At the team-level, scholars have used knowledge recombination insights to examine how teams should be configured in a way that maximizes the quality and quantity of new inventions (e.g. Bercovitz & Feldma, 2011; Taylor & Greve, 2006; Wang, Van de Vrande, & Jansen, 2017), focusing for instance on the presence of generalists in the team (Melero & Palomeras, 2015). Similarly, at the individual-level, scholars have argued that inventors develop certain abilities that allow them to generate more valuable component combinations than others (e.g. Boh *et al.,* 2014; Fleming, Mingo, & Chen, 2007; Gruber, Harhoff, & Hoisl, 2013).

Clearly, knowledge recombination has been widely-adopted as a mechanism to explain variance in inventive output. Despite this, we observed that the majority of studies have treated knowledge recombination rather superficially in conceptual and empirical terms, sticking to tenets of knowledge recombination that are already well-established. The problem with this research approach is that, by sticking to the well-trodden path, most studies make few efforts to advance our current understanding of knowledge recombination. At the same time, examining the core literature on knowledge recombination, in which fundamental aspects of this concept are studied in-depth (e.g. Fleming, 2001; Yayavaram & Ahuja, 2008; Wang *et al.,* 2014), we quickly learn that knowledge recombination is still poorly understood in many important areas (Savino *et al.,* 2017). Our main research objective in this dissertation is therefore to substantially advance our understanding of knowledge recombination, creating new insights about the origins of new inventions.

To fulfill this research objective, we conduct three empirical projects on knowledge recombination in the fuel cell industry, developing research questions that help us to venture beyond what we already know about this concept. In chapter 2, challenging the widely-held assumption that components' recombinant value is pre-determined at creation, we join an emerging research stream on knowledge reuse trajectories and argue that a component's contemporary recombinant value largely depends on how recently it was reused. In chapter 3, arguing that knowledge pool size and diversity are not the only drivers of knowledge recombination in R&D alliances, we explore the knowledge recombination benefits and liabilities of alliance partners' knowledge pool applicability. In chapter 4, questioning the implicit assumption that going-together always outperforms going-alone in terms of generating high-quality technological solutions, we argue that idiosyncratic combinative capabilities play a pivotal role in helping organizations reap the knowledge recombination benefits of going-together. To explain this research approach in more detail, we provide an overview of the three empirical projects in the following section (see Figure 1.1).

Figure 1.1. Overview of dissertation

	Chapter 2 **Recombinant lag and the technological value of inventions**	**Chapter 3** **Knowledge pool applicability in R&D alliances**	**Chapter 4** **Going-together in challenge-based R&D projects**
Core research gap	Recency of component reuse influences components' recombinant value	Knowledge pool applicability of alliance partners drives interfirm recombination	Only organizations with particular abilities can realize recombination benefits of going-together
Core knowledge recombination insight	Components' recombinant value changes over time through reuse	Components differ in terms of applicability	Potential recombinant opportunities are not always equal to realized recombinant opportunities
Outcome variable	Value of new combination	Recombination of partners' component knowledge	Value of new combination
Main data	Fuel cell patents Wind energy patents (1959-2007)	Fuel cell patents Fuel cell R&D alliances (1993-2007)	Challenge-based R&D projects on hydrogen and fuel cell technologies (2003-2016)

1.1. Overview of three empirical projects

1.1.1. Project 1: Recombinant Lag and the Value of Inventions

In chapter 2, we present the results of the first project. In this project, we study how attributes of recombined components influence the technological value of new inventions (Capaldo, Lavie, & Petruzzelli, 2017; Li, Vanhaverbeke, & Schoenmakers, 2008). Knowledge recombination research has traditionally focused on original attributes of components (Phene, Fladmoe-Lindquist, & Marsh, 2006; Miller, Fern, & Cardinal, 2007; Rosenkopf & Nerkar, 2001) – i.e. attributes that were embedded into the component at the time of creation. From this perspective, a component's recombinant value is largely pre-determined at creation. An emerging stream of research on knowledge reuse trajectories, however, relaxes this assumption, and argues that components' recombinant value may change considerably over time through component reuse – i.e. the integration of components into new combinations (Fleming, 2001; Katila & Chen, 2008; Yang, Phelps, & Steensma, 2010). Using organizational learning theory (Argote & Miron-Spektor, 2011), they argue that each instance of reuse produces, what we refer to as, reuse information flows – i.e. information flows that are generated when components are reused in different combinations (Katila & Chen, 2008). Inventors can access these reuse information flows in order to improve their understanding of how particular components should be applied most effectively in new combinations (Fleming, 2001; Katila & Chen, 2008).

Research on knowledge reuse trajectories has extensively focused on the frequency of reuse, arguing that the magnitude of reuse information flows influences the recombinant value of components (Fleming, 2001; Katila & Ahuja, 2002). Contributing to this emerging stream of research, our specific research objective in the first project is to examine the largely neglected temporal dimension of reuse, introducing the concept of recombinant lag – i.e. the time that recombined components have remained unused. We hypothesize that recent reuse triggers a rejuvenation effect, embedding the component in the state-of-the-art of technology by creating information about its most up-to-date applications in knowledge recombination. Consequently, we expect that recent reuse improves inventors' ability to generate inventions with higher technological value. Moreover, we explore whether this main relationship is moderated by the frequency at which recombined components were previously reused. These expectations are explored using data on 21,117 patent families from the fuel cell industry pertaining to 139 consolidated firm applicants. Additional data from a post-hoc exploratory analysis are also used, including an inspection of fuel cell literature, an interview with a fuel cell expert, and additional patent data from the wind energy industry.

1.1.2. Project 2: Knowledge Pool Applicability in R&D Alliances

In chapter 3, we present the results of the second project on the topic of knowledge recombination within interfirm R&D alliances. R&D alliances are often conceived as learning vehicles which firms can use to access novel component knowledge from other firms (Rosenkopf & Almeida, 2003). Alliance scholars claim that, by collaborating with external partners that possess larger and more technologically diverse knowledge pools, the focal firm gains new opportunities to generate component combinations (Fleming, 2001; Phelps, 2010; Schilling & Phelps, 2007). However, inspecting recent knowledge recombination literature (e.g. Dibiaggio, Nasiriyar, & Nesta, 2014; Wang *et al.,* 2014), we notice that, next to quantity and diversity, the applicability of components is also regarded as an important driver of knowledge recombination activities. Alliance research, however, tends to ignore variance in components' level of applicability. Therefore, we introduce the concept of knowledge pool applicability – i.e. the extent to which components situated in the knowledge pool can be used in different application domains, studying its impact on the focal firm's intensity of partner-specific recombination.

From the focal firm's perspective, we expect that it is highly beneficial to collaborate with a partner that has higher knowledge pool applicability, at least up until a certain point. In particular, by collaborating with such a partner, the focal firm gains considerable flexibility in its pursuit of recombination opportunities (Yayavaram & Ahuja, 2008). At the same time, beyond a certain threshold value, we expect that the partner's knowledge pool applicability will reduce the focal firm's partner-specific recombination, since there are significant learning complexities associated with very widely-applicable component knowledge (Hargadon & Sutton, 1997). Next to the partner's knowledge pool applicability, we also consider the knowledge recombination implications of the focal firm's own knowledge pool applicability. We hypothesize that, equipped with prior experience building widely-applicable component knowledge, the focal firm is able to more flexibly and effectively engaging in knowledge recombination within the partner's knowledge pool, increasing its intensity of partner-specific recombination. We explore these two expectations using a highly unique dataset on the R&D alliances of 88 consolidated focal firms in the fuel cell industry over a 15-year time period (1993-2007), using patent citations to track knowledge recombination between the focal firm and its partners within 461 R&D alliance dyads.

1.1.3. Project 3: Going-together in Challenge-Based R&D Projects

In chapter 4, we present the results of the third project in which we examine the difference in problem-solving performance between going-together and going-alone strategies in challenge-based R&D projects. In recent years, numerous large-scale government-funded programs aimed at addressing society's greatest challenges, such as climate change, have been initiated (Howard-Grenville, Buckle, Hoskins, & George, 2014; Olsen, Sofka, & Grimpe, 2016). Within the scope of these programs, different types of organizations participate in challenge-based R&D projects to solve extant technological problems within a specific field. In grand challenges literature, there seems to be an implicit assumption that going-together strategies, in which the focal organization formally involves partners in the project, always outperform going-alone strategies in terms of generating high-quality technological solutions. The underlying mechanism is that going-together creates important knowledge recombination opportunities, as it allows merging partners' heterogeneous knowledge pool to generate new technological solutions (Das & Teng, 2000).

In this project, using insights from the knowledge-based view (Galunic & Rodan, 1998; Kogut & Zander, 1992), we argue that organizations require unique abilities to identify, retrieve, and recombine partners' component knowledge in order to reap the knowledge recombination benefits of going-together (Zahra & George, 2002). To explore this contention, we first formulate a baseline hypothesis in which we expect that going-together, on average, yields higher problem-solving performance than going-alone. In the three subsequent hypotheses, we argue that three distinct characteristics of the focal organization – institutional background, internal knowledge pool size, and challenge-based R&D project portfolio size – influence the size of the problem-solving performance gap between going-together and going-alone. To study these hypotheses, we analyse a highly unique dataset comprising detailed project-level information on 414 challenge-based R&D projects within the U.S. Department of Energy's Hydrogen and Fuel Cells Program over a 14-year time period (2003-2016).

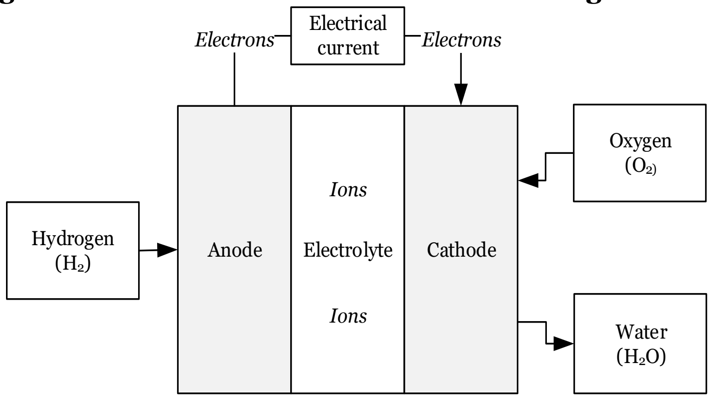
1.2. Empirical setting: The fuel cell industry

In the following section, we present some details regarding the fuel cell industry, which is the empirical setting of this dissertation. In particular, since we rely extensively on examples from the fuel cell industry in each empirical project, we first provide a short explanation of what a basic fuel cell system looks like. Subsequently, we discuss three factors that motivated our choice for this industry as the focal empirical setting of this dissertation.

1.2.1. Basic overview of fuel cell system

In its most basic form, a single fuel cell comprises an anode, a cathode, and an electrolyte sandwiched in-between (see Figure 1.2) (Steele & Heinzel, 2001). In a fuel cell, hydrogen molecules enter at the anode, where they are catalytically separated into negatively charged electrons and positively charged protons (i.e. hydrogen ions) by a platinum catalyst. The separated electrons travel from the anode side of the fuel cell to the cathode side through an external wire to generate an electrical current. The protons travel from the anode side of the fuel cell to the cathode side by permeating through the electrolyte (which is typically made of a solid polymer membrane or a solid oxide). Oxygen molecules enter at the cathode side of the fuel cell, where they react with the electrons and protons, creating potable water as a residual at the cathode side. As such, a fuel cell can generate electricity for as long as reactants (i.e. hydrogen and oxygen) are supplied to it, with water and heat as its residuals.

Figure 1.2. Basic chemical reaction inside single fuel cell



Since a single fuel cell typically does not generate enough voltage, multiple fuel cells are usually combined, creating a so-called 'fuel cell stack'. Special techniques have been developed over the years to stack fuel cells effectively, ensuring that reactants are distributed evenly across the single fuel cells, operating temperatures remain uniform, and no gases leak from the stack. The fuel cell stack is situated at the heart of the fuel cell system, as this is where the electrochemical reaction takes place that generates electricity. However, a fuel cell stack, in and of itself, does not constitute a fuel cell system. Instead, a fully-integrated fuel cell system usually comprises other crucial subsystems. Importantly, hydrogen tanks (to store pure hydrogen that is supplied to the fuel cell stack) or fuel reformers (to reform a hydrocarbon or alcohol fuel into reformate hydrogen that can be used in the fuel cell) are generally integrated with the fuel cell stack, such that reactants can be readily fed into the stack. In turn, the oxygen that is supplied to the fuel cell usually simply comes from the air (for example, in many fuel cell cars, there are inlets at the frontside of the car that allow oxygen to easily travel to the fuel cell stack). Moreover, other balance-of-plant components, such as fans (to circulate oxygen and/or cool down the fuel cell system), sensors (e.g. to detect impurities in hydrogen fuel), and heat exchangers (e.g. to cool the fuel cell stack, to feed heat from the fuel cell stack to the fuel reformer) are often used to support the overall functioning of the fuel cell system (Sharaf & Orhan, 2014). The compiled fuel cell system can be integrated into larger systems, such as large- and small-scale power plants, light-duty vehicles, heavy-duty vehicles, airplanes, boats, unmanned aerial vehicles (UAV), etc. As such, using hydrogen and oxygen from the air, fuel cell systems can generate electricity which can power a wide array of devices.

1.2.2. Motivation to study the fuel cell industry

We chose the fuel cell industry as the empirical setting of this dissertation for three principal reasons: (i) importance of interorganizational collaboration, (ii) availability of rich archival quantitative data, and (iii) diversity of organizations involved. First, since we study interorganizational collaboration activities in chapters 3 and 4, we needed to find an industry in which these activities are prevalent and consequential. In the fuel cell industry, interorganizational collaboration is seen as crucial for generating improved fuel cell technologies (Hellman & Van den Hoed, 2007). Not only are resources and capabilities heterogeneously distributed amongst organizations, there is also much uncertainty about the future of the technology, requiring organizations to actively engage in interorganizational collaboration to keep pace (Schilling, 2015). The necessity of interorganizational collaboration for developing valuable fuel cell technologies was also emphasized by several leading industry practitioners. For example, Carlos Ghosn (then COO of Nissan) stated that: “There is no one car company working on fuel cells on its own [...] This is a very complex technology, there are a lot of technical challenges to be overcome (The Daily Yomiuri (Tokyo), 1999)”. Similar opinions were voiced by Matthew Fronk, technical director of the fuel cell program of Delphi Automotive Systems/General Motors between 1990 and 2009, when discussing Delphi’s collaboration with Exxon and ARCO: “Building an integrated gasoline fuel processor and fuel cell system presents formidable technical challenges [...] our joint research initiative brings together expertise in automotive technology, electric propulsion systems, and fuel processing to address technical issues involved in converting liquid fuels to hydrogen in a compact, vehicle-scale reformer. (PR Newswire, 1997)".

Second, quantitative archival data is extensively available about fuel cell and associated hydrogen technologies. Organizations in the fuel cell industry invest considerably in patenting newly-created inventions, leaving behind a trail of inventive activities that we can easily track. In fact, for many years, patenting activities in fuel cell technology ranked among the highest in clean energy technologies (Albino, Ardito, Dangelico, & Petruzzelli, 2014). Since we rely on patent data to track knowledge recombination activities in chapters 2 and 3, this aspect of fuel cell inventive activities was instrumental to our decision to examine the fuel cell industry. Similarly, data on interorganizational collaborative activities in the fuel cell industry is widely-available. R&D alliance activities between fuel cell organizations have been extensively documented, ensuring that we can track interorganizational collaboration patterns over long periods of time. This is important, as we need to pinpoint the starting and ending date of R&D alliances as accurately as possible for the second project. Similarly, data on challenge-based R&D projects, which we study in the third project, is easy to access. Other data for this empirical project, such as the configuration and problem-solving performance of challenge-based R&D projects, is also easy to retrieve. Hence, for the three projects in this dissertation, we are able to use extremely rich quantitative data to explore our research questions.

Third, an important advantage of studying the fuel cell industry is the sheer diversity of organizations involved in this industry (Hellman & Van den Hoed, 2007). Some of the largest automotive (e.g. Toyota, Honda, Daimler, Renault, General Motors, Ford), chemical (e.g. 3M, BASF, Dow Chemical, Showa Denko), oil & gas (e.g. Shell, ExxonMobil, Air Products & Chemicals, Osaka Gas), heavy equipment (e.g. IHI, Mitsubishi Heavy Industries), electronics (e.g. Samsung Electronics, Toshiba, Panasonic), ceramics (e.g. Toto, Corning), and rare metal (e.g. Engelhard, Johnson Matthey) firms have (had) a strong stake in fuel cell technology. Besides this, numerous dedicated fuel cell manufacturers (e.g. Plug Power, Ballard Power Systems, Fuelcell Energy, Hydrogenics) have been responsible for important advances in the technology. Universities and research institutes are also heavily invested in fuel cell technology, with prominent U.S. (e.g. Stanford University, Gas Technology Institute, Georgia Tech) and European (e.g. Jülich Research Centre, Energy Research Centre of the Netherlands, Alternative Energies and Atomic Energy Commission) research organizations playing an important role in driving technological change in fuel cells. Altogether, the diversity of players in the fuel cell industry ensures sufficient variance in the capabilities and resources of organizations that we study in each project, allowing us to adequately test our hypotheses.