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

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Chapter 7. English Summary

Knowledge recombination – i.e. the recombination of existing knowledge components in order to generate new inventions – underlies much of technological growth. By studying knowledge recombination, we are able to gain important new insights into when and how valuable new inventions are generated. In extant literature, numerous studies rely on knowledge recombination, principally using it to explain performance heterogeneity across different levels of analysis, such as the individual, team, or organization. Despite the fact that knowledge recombination features so prominently in the conceptual/empirical framework of extant studies, few studies make serious attempts to advance our understanding of this concept beyond what is already known about it. Simultaneously, in the core literature that examines knowledge recombination, it is often recognized that knowledge recombination is still poorly understood in many areas. The core objective of this dissertation is therefore to substantially advance our understanding of knowledge recombination, creating new insights about the origins of new inventions. To address this core research objective, we conduct three empirical projects on knowledge recombination, using novel and extensive data from the fuel cell industry.

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

In the first project, we study how attributes of recombined components influence the technological value of new inventions. Knowledge recombination research traditionally focuses on original knowledge component attributes, assuming that components' recombinant value is largely pre-determined at creation. In contrast, joining an emerging literature stream on knowledge reuse trajectories, we argue that when components are used in different combinations over time, their recombinant value may change considerably. Contributing to this latter stream of literature, we focus on the temporal dimension of component reuse and introduce the concept of recombinant lag – i.e. the time that recombined components have remained unused.

Making use of insights from organizational learning theory, we first hypothesize that recent reuse creates learning opportunities about a component's contemporary applications in recombination, effectively rejuvenating its recombinant potential. Hence, recent reuse is expected to be associated with inventions with higher technological value. In the second hypothesis, we predict that this main relationship is moderated by the frequency at which recombined components were previously reused. In particular, we posit that when components were reused more frequently, ambiguities associated with the rejuvenation effect of recent reuse are reduced, augmenting its value-enhancing effect.

To test these hypotheses, we analyze 21,117 patent families from the fuel cell industry. Our findings indicate that there is an unexpected U-shaped relationship between recombinant lag and the value of inventions. Moreover, this main relationship is moderated by components' prior frequency of reuse. Subsequently, we conduct post-hoc exploratory data analyses, advancing the concept of dormant component knowledge – i.e. valuable components that have remained unused prolongedly – as a potential explanation for these unexpected patterns. We are also able to produce first indications for the generalizability of these unexpected findings, collecting additional patent data from the wind energy industry.

With these findings, we contribute in two major ways to extant knowledge recombination literature. First, exploring distinct theoretical mechanisms associated with frequency and recency of reuse, we show that not only the magnitude of reuse information flows (i.e. frequency of reuse), but also the timing of creation of these reuse information flows (i.e. recombinant lag) is a crucial determinant of a component's current recombinant value. Second, we contribute to the literature that examines the temporal dimension of knowledge recombination. Specifically, controlling for component age, we find a distinct and robust influence of recombinant lag on the technological value of new inventions, indicating that these two dimensions of time complement each other.

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

In the second project, we study factors that allow focal firms to more intensively recombine the component knowledge of R&D alliance partners. Using knowledge recombination insights, alliance scholars often argue that, by means of collaborating with external partners that possess larger and more technologically diverse knowledge pools, the focal firm obtains valuable new opportunities to generate component combinations. Inspecting recent knowledge recombination literature, however, we find that studies tend to focus more on the applicability of components, rather than solely their quantity or diversity. Interestingly, however, alliance research largely neglects that there is substantial variance in components' level of applicability. To address this critical research gap, 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 – and examine its influence on the focal firm's recombination of R&D alliance partners' components.

Relying on emerging knowledge recombination insights, we first hypothesize the existence of an inverted U-shaped relationship between the partner's knowledge pool applicability and the focal firm's intensity of partner-specific recombination. We argue that, initially, partner's knowledge pool applicability provides flexibility to the focal firm in terms of where and how it may apply components accessed from the partner. However, beyond a certain threshold value, it is expected that important learning complexities associated with overly-applicable component knowledge emerge, reducing partner-specific recombination amply. In the second hypothesis, we shift the focus towards the focal firm's own knowledge pool applicability. We hypothesize that, having previously built widely-applicable component knowledge, the focal firm is able to more flexibly and effectively engage in knowledge recombination within the partner's knowledge pool, increasing its partner-specific recombination.

To test these two hypotheses, we analyse 461 R&D alliance dyads of 88 firms in the fuel cell industry. Our findings provide strong support for the first hypothesis, showing that partner's knowledge pool applicability has an inverted U-shaped relationship with the focal firm's partner-specific knowledge

recombination. In contrast to our expectations, however, we find that the knowledge pool applicability of the focal firm has a U-shaped relationship with its partner-specific recombination.

These findings contribute in two ways to extant alliance literature. First, we shift the theoretical lens from the aggregate knowledge pool to individual components within the knowledge pool. Rather than to assume broad applicability of components from aggregate knowledge pool characteristics (e.g. diversity or size), we emphasize the importance of examining whether individual components are, in fact, broadly applicable or not. Second, we show the importance of theorizing on capabilities that allow the focal firm to engage more intensively engage in recombination of its R&D alliance partners' component knowledge. In sum, our findings indicate the importance of taking an in-depth knowledge recombination perspective to examining the performance implications of R&D alliances.

7.3. Project 3: Going-Together in Challenge-Based R&D Projects

In the third project, we study the problem-solving performance implications of going-together and going-alone strategies in challenge-based R&D projects. Recent years have seen a rapid increase in the number of large-scale government-funded programs that are aimed at addressing society's greatest challenges, such as climate change and population aging. Within these programs, organizations, ranging from firms to universities, engage in challenge-based R&D projects to attempt to solve extant problems within a specific field. In the literature on grand societal challenges, an implicit assumption is often made that going-together strategies – i.e. projects in which the focal organization formally involves partners – always lead to higher quality technological solutions than going-alone strategies – i.e. projects in which the focal organization operates independently. These performance differences are often explained by pointing to the possibility of recombining heterogeneous component knowledge of partners through collaboration.

In this project, using insights from the knowledge-based view, we deviate from these prior studies and argue that not every organization can actually reap the knowledge recombination benefits of going-together strategies. More specifically, we argue that organizations require abilities to identify, retrieve, and recombine partners' component knowledge in order to reap the knowledge recombination benefits of going-together. Based on this, we develop theoretical arguments to suggest that three distinct characteristics of the focal organization – institutional background, internal knowledge pool size, and challenge-based R&D project portfolio size – influence whether going-together strategies outperform going-alone strategies, in terms of problem-solving performance.

To test our 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). Our findings provide evidence that, on average, going-together strategies outperform going-alone strategies. Noteworthily, however, we find that firms perform considerably better when going-together rather than going-alone, but research organizations do not. Moreover, we find that the problem-solving performance gap between going-together and going-alone strategies widens substantially when the focal organization has a larger internal knowledge pool. Finally, contrary to expectations, our findings indicate that the focal organization's R&D project portfolio size initially increases the positive problem-solving performance gap between going-together and going-alone but, beyond a certain point, decreases it.

Jointly, these findings contribute to extant research on grand challenges and open innovation. Specifically, our findings call into question the oft-assumed advantages that prior research associates with going-together strategies, when it comes to addressing extant technological problems within a field. We find that, for many types of organizations, going-alone strategies seem to perform equally well in terms of problem-solving performance than going-together strategies.

7.4. Conclusion

This dissertation develops several important theoretical contributions that help us to better understand the process of knowledge recombination. First, we underline the fact that components do not have a recombinant value that is pre-determined at creation; instead, components' recombinant value may change considerably over time through reuse. In this respect, we make an important contribution by arguing that, next to the frequency of reuse of components, their recombinant lag should also be taken into account. Second, we point out that, when examining the performance implications of R&D alliances, it can be useful to examine the applicability of individual components that comprise the knowledge pool of partners, rather than to solely focus on aggregate knowledge pool characteristics, such as size or diversity. In support of this, controlling for the knowledge pool size, diversity, and distance of R&D alliance partners, we consistently found a strong effect of knowledge pool applicability on the focal firm's recombination of partner's component knowledge. Third, in contrast to prior research which often assumes a somewhat direct relationship between partners' knowledge inputs and the focal organization's own knowledge outputs, we found that organizations require idiosyncratic combinative capabilities in order to considerably benefit from interorganizational collaboration.

This dissertation also carries important practical contributions. First, following the emerging open innovation paradigm, we point out that it is important that information flows that are produced when new inventions emerge diffuse accurately and rapidly to other inventors, facilitating the subsequent generation of valuable inventions. Moreover, our findings indicate that interorganizational collaboration strategies may play a decisive role in helping organizations detect new sources of component knowledge and generate high-quality technological solutions. Second, we argue that it is important to implement strong resource management strategies in order to generate valuable new inventions. In the first project, we found that knowledge components which have remained unused for prolonged periods of time, represent unexpected sources of value for knowledge recombination. Hence, we encourage organizations to regularly reevaluate the existing knowledge stock such that these types of components can be unearthed,

leading to considerable technological value realization. Moreover, findings from the second and third project suggest that prior experience with creating new inventions needs to be adequately managed by the focal organization, such that it can be deployed in order to improve subsequent knowledge recombination efforts.