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Internal or external spillovers—Which kind of knowledge is more likely to flow within or across technologies

Benedikt Battke[a,*], Tobias S. Schmidt[b], Stephan Stollenwerk[a], Volker H. Hoffmann[a]

[a] Swiss Federal Institute of Technology Zurich (ETH Zurich), Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56/58, CH-8092 Zurich, Switzerland
[b] Swiss Federal Institute of Technology Zurich (ETH Zurich), Department of Humanities, Social and Political Sciences, Haldeneggsteig 4, CH-8092 Zurich, Switzerland

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ABSTRACT

Literature on technological change has highlighted the importance of the cumulative character of knowledge. Typically, knowledge produced in a technology inspires subsequent knowledge within the same technology. But knowledge spillovers across technologies can also occur, i.e., technologies can benefit from knowledge that originated in other technologies. Such spillovers support technological variety, one potential goal of technology policy. The extant literature on knowledge diffusion, however, has not been able to explain which characteristics of knowledge increase the likelihood that knowledge will remain within its own technological field or spill over to other technologies. To address this gap, in this paper we test a set of hypotheses on how the diversity of prior art and the degree of technological centrality of knowledge affect the subsequent flow of this knowledge within and across technologies. Drawing upon a comprehensive set of more than 40,000 battery patents, we show that knowledge that is based on comparably less diverse previous knowledge is more likely to be related to intra-technology knowledge flows, and less likely to be related to knowledge spillovers to other technologies. Similarly, compared to peripheral knowledge, core knowledge is more likely to go along with intra-technology knowledge flows and less likely to spill over to other technologies. These findings have important implications for the design of science, technology and innovation policy. Policy measures that encourage the development of specialized and core knowledge are likely to foster the development of stable technological trajectories, whereas measures targeted at developing diversified and peripheral knowledge more strongly contribute to technological variety.

1. Introduction

Technological change is a critical determinant of economic development (Schumpeter, 1934). A key characteristic of technological change is that technological innovation builds upon prior existing knowledge (Dosi, 1982). Technological evolution is typically shaped by problem solving activity which integrates knowledge from the same technology, leveraging the cumulative character of knowledge. Thus, typically the knowledge produced in a technology remains within the same technology. However, knowledge spillovers across technologies also occur, i.e., knowledge can be valuable for technologies in different technological domains. Consequently, while some knowledge has the tendency to generate knowledge flows mostly within the same technology, reinforcing the existing technological trajectories and thereby locking-in specific technologies, other knowledge generates spillovers across technologies and thus has the potential to increase technological variety (Van den Bergh, 2008; Schoenmakers and Duysters, 2010). From a policy perspective, this is of high relevance as technological variety and lock-in of technologies are prominent themes in both the practical and theoretical debate (Del Río González, 2008). In this paper, we aim to improve the understanding of which kind of knowledge has the tendency to generate knowledge flows within and across technologies.

Previous literature on technological knowledge flows has focused on the question of which knowledge has a high propensity to generate subsequent knowledge flows, with the strength of this propensity typically being used to approximate the value or radicalness of an invention (Schoenmakers and Duysters, 2010; Nemet, 2012; Nemet and Johnson, 2012). These studies analyzed, among others, the effect of the diversity of prior art (i.e., the integration of different kinds of prior knowledge) on the totality of knowledge flows, yet they did not distinguish the technologies benefiting from these knowledge flows. In other words, the previous literature did

* Corresponding author. Fax: +41 44 632 10 45.
E-mail addresses: bbattke@ethz.ch, b.battke@gmail.com (B. Battke).

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not distinguish whether these knowledge flows remain within the same technology, thereby reinforcing the established trajectory, or whether the knowledge was transferred to different technologies in the form of knowledge spillovers. Only very recently, Noailly and Shestalova (2013) presented a discussion paper that differentiates knowledge flows within and across technologies. Yet they did not investigate what characteristics of knowledge lead to different knowledge flows. Consequently, we lack an understanding of which characteristics of knowledge increase the likelihood of knowledge flows within or across technologies.

To address this gap, this paper investigates how two important characteristics of knowledge, namely (i) its diversity of integrated prior art and (ii) the degree of its technological centrality, affect the likelihood of generating subsequent knowledge flows within or across technologies. We define the differentiation between knowledge flows within and across technologies as the "direction of knowledge flows."

The first characteristic, the diversity of integrated prior art, describes whether the technological knowledge is specialized or diversified. "Specialized knowledge" mainly integrates prior art (i.e., prior existing knowledge) from the same technology; "diversified knowledge" mainly integrates prior art from different technologies. Thus far, studies have analyzed the effect of this characteristic on the totality of knowledge flows, without differentiating their direction (Lettl et al., 2009; Schoenmakers and Duysters, 2010; Nemet, 2012; Nemet and Johnson, 2012). Yet, these studies have not come to conclusive empirical results on the effects of the diversity of integrated prior art. The second characteristic builds upon the product architecture literature and describes how central the knowledge is to a technology. Specifically, it distinguishes different centrality levels, which span from "core level knowledge" (i.e., knowledge on core components of a technology) to "peripheral level knowledge" (i.e., knowledge on peripheral components of a technology). While the product architecture literature has proven its value for several aspects of technical change and innovation (Tushman and Rosenkopf, 1992; Murmann and Frenken, 2006), it has not yet been used in studies explaining knowledge flows within or across technologies.

In order to explore our research question, we investigate knowledge flows within and across three battery technologies (lead-acid, lithium-ion, and nickel). Batteries are chosen as a research case because of inventors' high propensity to patent knowledge on battery technologies and because of the comparability in the product architecture of batteries, which facilitates our analysis. We measure knowledge flows using forward citations between battery patents, employing a comprehensive data set consisting of 42,619 patents and 106,548 forward citations. To analyze this data set, we use a negative binomial regression model.

Our analysis yields three main contributions. First, by differentiating knowledge flows by their direction, we show that different mechanisms determine knowledge flows within and across technologies. This helps to explain contradictory empirical results in previous studies on technological knowledge flows. Second, we link the existing literature on knowledge flows, which has mostly centered on the diversity of prior art, to the literature on product architecture introducing the centrality of the knowledge as a second explanatory factor. Our analysis indicates that the degree of centrality of knowledge is highly relevant to knowledge flows and improves the understanding of technological knowledge diffusion. Third, we discuss the implications of our analysis for the literature on knowledge diffusion, and, more generally, on technological evolution, as well as for technology policy.

The remainder of this article is structured as follows: Section 2 sets out our theoretical argumentation and develops hypotheses on the diversity of prior art (Section 2.1) and the degree of technological centrality (Section 2.2) of knowledge. Section 3 describes the scope, theoretical sampling, data set and methodology employed to test the hypotheses. The regression results are presented in Section 4 and discussed in Section 5, where implications for theory and policy are derived. The paper ends with a short conclusion in Section 6.

2. Theory and hypotheses

It has long been acknowledged by scholars that the construct of knowledge plays a key role in attempts to explain the origins and dynamics of technological change. Based on the early work of Gilfillan (1935) and Usher (1954), research has tried to track the origins of inventions, leading to a large number of studies dealing with knowledge flows, knowledge spillovers and the characteristics of knowledge. Within this area, an important concept is that novel technologies build upon and recombine existing knowledge from near and distant technologies. Consequently, existing knowledge can be transferred to subsequent knowledge in the same or different technologies, a fact that can be described by knowledge flows within and across technologies. In the following, we discuss two characteristics of knowledge, the diversity of prior art and the degree of technological centrality, which are likely to affect the likelihood that flows occur within or across technologies.[1]

Fig. 1 gives an overview of the design of the study and the nomenclature used in the remainder of the paper. In our study, knowledge flows refer to knowledge that is transferred to subsequent knowledge. The *direction* differentiates knowledge flows according to the distance of the recipient technology, i.e., it differentiates knowledge flows within and across technologies. To improve the understanding of the drivers of the direction of knowledge flows, we build hypotheses on the effect of the diversity of prior art (Section 2.1) and the degree of technological centrality (Section 2.2) of knowledge.

2.1. The effect of the diversity of prior art

The first knowledge characteristic of interest for our study is the diversity of integrated prior art, which we define as the degree to which a technology integrates previously existing knowledge that originated in the same or different technologies. The extant literature has mostly been concerned with the question of how the diversity of prior art affects the likelihood of generating a high amount of knowledge flows in order to approximate the value or radicalness of an invention. In particular, previous studies have tested whether *diversified knowledge*, i.e., knowledge that primarily integrates prior art from distant technologies, or *specialized knowledge*, i.e., knowledge that primarily integrates prior art from the same technology, exerts a stronger effect on subsequent knowledge flows (Benner and Waldfogel, 2008; Gilsing et al., 2008). As we will show in the following, thus far the literature has not developed a conclusive answer to this question either through theoretical reasoning or empirical analyses.

Scholars arguing that diversified knowledge is more likely to generate knowledge flows than specialized knowledge typically refer to the positive impact of combining existing knowledge from different areas into new artifacts (Schumpeter, 1934; Gilfillan, 1935; Nelson and Winter, 1982; Arthur, 1989; Nemet and Johnson, 2012). Usher (1954) described the innovation process as "cumu-

[1] Although both explanatory factors describe continuous characteristics, we use extreme points (i.e., specialized vs. diversified knowledge, core vs. peripheral knowledge) in order to derive the theoretical reasoning. In the analysis we differentiate the explanatory factors the diversity of prior art and the degree of technological centrality of knowledge into three and for variables, respectively.