Characteristics of codified knowledge and replication-imitation speed differentials

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Abstract

Purpose – The purpose of this paper is to empirically investigate knowledge replication-imitation speed differentials in the context of patents as the target knowledge.

Design/methodology/approach – This study analyzes patent citations in the electric digital data processing class employing an accelerated failure-time model.

Findings – This study finds that replicators can turn the private aspect of knowledge into an advantage against imitators with respect to the speed of knowledge transfer, even after the knowledge is codified in a patent. Specifically, being a replicator provides no knowledge transfer speed advantage over imitators. Instead, a joint consideration of knowledge characteristics and organizational boundaries is necessary when explaining knowledge replication-imitation speed differentials. Thus, "organizational advantage" in knowledge transfer is knowledge characteristic-specific rather than general.

Originality/value – This study illuminates the differential effects of organizational boundaries on knowledge transfer by investigating both replication and imitation in conjunction with each other, which has been a weakness in previous studies. This study also investigates knowledge transfer speed, another void in extant research.

Keywords Knowledge-based view, Knowledge characteristics, Replication-imitation dilemma, Knowledge transfer speed, Organizational advantage

Paper type Research paper

1. Introduction

Knowledge can be a source of competitive advantage when transferred quickly inside an organization, while imitation by the outsiders is deterred. If knowledge is the primary resource upon which competitive advantage is founded, its transferability determines the period during which its possessor can earn rents from it (Spender, 1996). Firms are therefore concerned about knowledge transfer speed (Eisenhardt and Santos, 2002; Zander and Kogut, 1995; Zahra *et al.*, 2000), striving to increase their knowledge replication speed while slowing competitor imitation[1]. Knowledge transfer speed can enable firms to utilize first-in advantages (Bierly and Chakrabarti, 1996). Winning competition requires heterogeneity among resources and capabilities, which can be fostered by creating and replicating knowledge faster than competitors can imitate it (Kogut and Zander, 1993; Phene *et al.*, 2005). Several researchers even claim that acquiring knowledge faster than competitors may be the only way to obtain a sustainable competitive advantage (Paladino, 2008). However, few studies have investigated this dimension of knowledge transfer (Pérez-Nordtvedt *et al.*, 2008).

Knowledge typically transfers more easily inside an organization than across organizations (Baum and Ingram, 1998), leading to "organizational advantage" (Nahapiet and Ghoshal, 1998). Zellmer-Bruhn (2003) finds that best practices are more likely to be

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transferred between units belonging to the same organization than they are between units belonging to different organizations. Irwin and Klenow (1994) demonstrate that, though knowledge transfers across semiconductor firms, companies learn thrice as much from their own experience as they do from other firms.

However, the organizational advantage may be substantially smaller with codified knowledge such as patents, since the risk of imitation is considerably greater (Olander *et al.*, 2014). Codification increases as the knowledge transfer target moves from the business model (Zott *et al.*, 2011), to strategy (Rivkin, 2001), to product (Damanpour *et al.*, 2009), and to patent (He *et al.*, 2006). Thus, patent-level knowledge may be the most vulnerable to rapid imitation because it represents public knowledge that can be accessed by imitators and replicators (Hoetker and Agarwal, 2007; Jasimuddin *et al.*, 2005).

Therefore, the vulnerability of codified knowledge to rapid imitation indicates the need to decouple the speed of replication and imitation. Our research question is therefore:

RQ1. Under what conditions are the internal replicators faster than the imitators in the transfer of codified knowledge such as patents?

By comparing the difference in speed between knowledge replication and imitation in the context of patents as the target knowledge, this study shows that organizational advantage is knowledge characteristic specific rather than general. In the patenting context, replication can be captured when a firm cites its own patents, while imitation can be detected when other firms cite the focal firm's patents. The speed of replication or imitation is defined as the time taken to apply for a patent citing one's own or a competitor's prior patent, respectively.

Addressing the research question requires that the same set of factors influencing the gap between replication and imitation must be investigated. However, most studies separately address replication (e.g. Szulanski, 1996; Winter and Szulanski, 2001) or imitation (e.g. Posen *et al.*, 2013; Rivkin, 2000). This is problematic, since addressing one problem (e.g. making replication easy) engenders another (i.e. imitation also becomes easy). Although a few empirical studies address replication and imitation simultaneously (Kogut and Zander, 1993; Zander and Kogut, 1995), they use different sets of factors to explain replication or imitation. To fill this research gap, we illuminate the differential effects of organizational boundaries on knowledge transfer by investigating both replication and imitation in conjunction with each other.

This study also addresses knowledge transfer efficiency by focusing on knowledge transfer speed. Despite the importance of efficiency and speed (Daft, 1998; Pérez-Nordtvedt *et al.*, 2008), most of the research has focused on the effectiveness of knowledge transfer (e.g. Dhanaraj *et al.*, 2004; Hoetker and Agarwal, 2007; Tsang, 2002).

The empirical results indicate that imitation is slower than replication when knowledge with certain characteristics (e.g. complexity and technological distance) transfers across firm boundaries. Organizational advantage can thus be sustained when transferring even highly codified knowledge when it has certain characteristics.

2. Theoretical background and hypothesis development

While patenting provides legal protection for intellectual property rights, it also renders a firm vulnerable to imitation by revealing secret knowledge. Hence, the efficacy of patents as a knowledge-protection mechanism has been questioned (Olander *et al.*, 2014). However, several studies find that patents can indeed reduce knowledge loss (Parker, 2012). A patent consists of not only explicit knowledge codified in a tangible form but also tacit knowledge possessed by people (Jasimuddin *et al.*, 2005). Despite considerable codification, patents contain private elements. Codifiability and tacitness are complements rather than substitutes (Balconi, 2002). Knowledge codification results only in a new combination of codified and tacit knowledge (Cowan and Foray, 1997). When the innovator's tacit knowledge is the real source of value generation, a patent may be insufficient for others to fully utilize the patented invention (Cowan *et al.*, 2000).

This study focuses on the characteristics of the knowledge in a patent that replicators or imitators seek to transfer. Knowledge characteristics are known to influence the time required to both replicate and imitate (Argote *et al.*, 2003). Zander and Kogut (1995) show that the degrees of codification and teachability influence knowledge transfer speed. This study considers the extent to which complexity, firm specificity, and technological distance influence knowledge stickiness and strengthen the private aspect of knowledge. These characteristics encompass most other dimensions of knowledge characteristics, for example, complexity may be highly associated with codifiability, observability, and tacitness.

2.1 *Complexity*

The greater the number and diversity of the dimensions involved in knowledge, the greater the complexity. Such dimensions include the number of technologies (Reed and DeFillippi, 1990), competencies (Rivkin, 2001), subtasks (March and Simon, 1958), and their interrelationships (Winter, 1987). The more complex knowledge is, the more difficult its transfer (King, 2007). Complex knowledge can be as inscrutable to the replicator as it is to the imitator (Makadok and Barney, 2001). Knowledge complexity increases ambiguity and thus negatively affects knowledge transfer (Van Wijk *et al.*, 2008). Knowledge complexity in patents and other public records are found to impede firms' full exploitation of their own inventions (Pérez-Nordtvedt *et al.*, 2008).

However, complex knowledge may be accessed more readily by internal replicators than by outside imitators given that internal entities have a higher likelihood of developing the capabilities required to alleviate the negative impact of complexity in knowledge flows. When knowledge consists of many related components, "a would-be imitator could understand most of the ingredients […] yet still fail to grasp the recipe" (Rivkin, 2000, p. 825). Similarly, in functioning complex systems with highly interdependent parts, understanding the whole system is required to achieve replication or imitation (Nelson and Winter, 1982). Knowledge that is interconnected with other elements of an organization is difficult for outsiders to understand and duplicate (Argote and Ingram, 2000; Teece *et al.*, 1997; Winter, 1987). Therefore, the organizational boundary is expected to function more favorably for the replicator than for the imitator when patented knowledge is complex:

H1. Replication is faster than imitation when codified knowledge is more complex.

2.2 *Firm specificity*

A firm can produce firm-specific knowledge by pursuing new knowledge that approximates its existing knowledge base and is tailored to its proprietary context (Wang *et al.*, 2009). The longevity of knowledge-based competitive advantage depends upon the organizational context in which that knowledge is embedded. Such knowledge is embedded in the relationships and principles of the organization and cannot be understood when separated from the supporting social fabric (Kogut and Zander, 1992).

Firm-specific knowledge is causally ambiguous because the link between knowledge and outcomes is difficult to comprehend for the knowledge holder, potential replicator, or imitator (Lippman and Rumelt, 1982). The more causally ambiguous the knowledge, the more difficult it is to replicate or imitate (Argote *et al.*, 2003). Therefore, firm-specific knowledge transfer might be equally challenging to replicators and imitators (Reed and DeFillippi, 1990).

However, King (2007) proposes that, when the organizational boundary is considered, knowledge idiosyncrasy poses a greater challenge to imitation than to replication.

Firm-specific knowledge is considered more useful to the firm than to outsiders because of its proximity to the firm's existing knowledge base and connection to its own business setting (Helfat, 1994). The outcome of firm-specific R&D can prove difficult to imitate. Knowledge that has important idiosyncratic elements is difficult for outsiders to reproduce (Helfat, 1994; King, 2007; Wang *et al.*, 2009). Therefore, the organizational boundary is expected to function more favorably for the replicator than the imitator when patented knowledge contains firm-specific elements:

H2. Replication is faster than imitation when codified knowledge is more firm specific.

2.3 Technological distance

Innovating firms face the choice of either integrating knowledge from distant knowledge domains or focusing on familiar domains (Rosenkopf and Nerkar, 2001). Firms tend to conduct local searches, whereby they direct R&D activity to their previous activities (Nelson and Winter, 1982). A firm's absorptive capacity (i.e. ability to assimilate and integrate new technological knowledge) is strongly associated with its past R&D. Because of the cumulative nature of absorptive capacity, a firm tends to maintain operations in a particular knowledge domain (Cohen and Levinthal, 1990). Knowledge identification and assimilation are simplified when new knowledge and the internal knowledge base contain similar elements (Ahuja and Katila, 2001; Schildt *et al.*, 2012). This applies to replicators and imitators equally. Rosenkopf and Nerkar (2001) empirically show that firms have difficulty assessing the value of their own knowledge in distant domains. Thus, the technological distance of knowledge is expected to negatively influence the speed of replication and imitation.

When interacting with technologically distant knowledge, however, the organizational boundary may be more advantageous to replicators. An innovating firm's ability to assimilate distant knowledge is determined by the relationship between its knowledge and that of the source (Lane and Lubatkin, 1998). As the distance between new and existing knowledge increases, the search scope expands, and the proportion of new knowledge requiring integration increases, resulting in technological and organizational challenges (Grant, 1996; Katila and Ahuja, 2002). For example, common technological interfaces may need to be established among knowledge elements, or networks of relations and communication may need to change (Henderson and Clark, 1990). In such cases, the organizational boundary can make a difference by providing a common code and language to replicators, facilitating the creation and adoption of new intellectual capital (Nahapiet and Ghoshal, 1998). Repeated interactions between members within the social community of replicators can assist in overcoming the influence of technological distance and allow a faster search for relevant information (Sorenson and Fleming, 2004). Therefore, the organizational boundary is expected to function more favorably for the replicator than the imitator when knowledge is distant from the current knowledge domain:

H3. Replication is faster than imitation when codified knowledge is more distant from the knowledge domain of the knowledge user.

3. Data and methodology

3.1 Data

This study employs National Bureau of Economic Research US patent citation data. Patent citations can provide information that captures the flow of knowledge (e.g. Jaffe and Trajtenberg, 2002; Vasudeva and Anand, 2011). Despite concerns about the potential noise in the patent citation data (Alcácer and Gittelman, 2006), patent citations are known to be associated with knowledge flows (Duguet and MacGarvie, 2005).

This study analyzes patents in the electric digital data processing (International Patent Classification: G06F) subclass filed through the US Patent and Trademark Office (USPTO) from 1996 to 2000. This patent subclass provides an ideal setting for testing the study's hypotheses. It is representative of computing and IT technology (Youtie *et al.*, 2008), where firms face fierce competition for innovative knowledge. The sample consists of 68,686 observations of 52,723 patents with at least one forward citation[2]. This empirical setting enables us to address the potential truncation issues with forward citations. Additionally, focusing on one industry can control for the possible influence of industry structure (Ahuja *et al.*, 2008).

3.2 Dependent variable

The dependent variable, time to forward citations, is measured as the median length of time (in years) between the patent application and forward citations made to the patent by replicators and imitators[3]. As older patents can receive more citations, this study employs a five-year window to address potential truncation issues (Lahiri, 2010).

3.3 Independent variables

Replicator is a binary variable capturing the organizational boundary – whether a forward citation is made by the same assignee or other assignees. Replicator equals 1 if the forward citation is made by the same assignee (i.e. replicator) and 0 if it is made by other assignees (i.e. imitator). Complexity captures the diversity of the patent classes in the backward citations of a focal patent and is measured using Blau's (1977) index:

$$\text{Complexity}_i = 1-\sum_{k=1}^{N_i}\left(\frac{\text{NCITED}_{ik}}{\text{NCITED}_i}\right)^2$$

where k represents the index of patent classes, Ni, the number of different classes to which the cited patents belong, and NCITED, the number of patents cited by the focal patent.

Firm specificity captures the knowledge's specificity to the focal firm's previous knowledge. It is measured as the ratio of self-citations to the total number of patents in the backward citations of a focal patent (Hoetker and Agarwal, 2007). Technological distance captures the distance in technological space between cited and citing patents and is measured as follows:

> If the citing patent is in the same 3-digit class (NCLASS) as the originating patent, then the distance between them, TECH, is set to zero; if they are in the same 2-digit class (CATCODE) but not in the same 3-digit class, then TECH = 0.33; if they are in the same 1-digit class (FIELD) and not in the same 2-or 3-digit class, then TECH = 0.66; if they are even in different 1-digit classes, then TECH = 1 (Jaffe and Trajtenberg, 2002, p. 61).

This study measures technological distance as the median value of the distance between the focal patent and its forward citations.

3.4 Control variables

Generality captures the dispersal of a focal patent's technology into different technological fields (Jaffe and Trajtenberg, 2002) and is measured as follows:

$$\text{Generality}_i = 1-\sum_{k=1}^{N_i}\left(\frac{\text{NCITING}_{ik}}{\text{NCITING}_i}\right)^2$$

where k represents the index of patent classes, N_i, the number of different classes to which the citing patents belong, and NCITING, the number of patents citing the focal patent.

Age is measured as the difference between the focal patent's application year and the median year of the patents the focal patent cites (Nerkar, 2003). Number of claims is measured as the total number of claims made with respect to a new patent. Number of patents in backward citations is measured as the number of citations to prior art. Number of forward citations is measured as the number of citations a patent receives (Singh, 2008). Membership in triadic patent families is a binary variable that captures a patent's membership in the triadic patent families (Lanjouw and Mody, 1996), which lists those patents filed at the European Patent Office, USPTO, and the Japan Patent Office. This variable addresses potential distortion from the home country bias toward the propensity of patent filing (Criscuolo, 2006). This study specifies two dummies, cited only by replicators and cited only by imitators, capturing the unique characteristics of the patents cited only by either replicators or imitators. Finally, year dummies are also included.

3.5 Methodology

The dependent variable is a time variable that is nonnegative, non-normally distributed, and censored. To address these characteristics, this study employs an accelerated failure-time (AFT) model (Cox and Oakes, 1984) with the Weibull distribution when estimating the effects of the covariates on the time to forward citations. The AFT model, employed in studies investigating temporal dimensions (e.g. Bercovitz and Mitchell, 2007), can be specified as follows:

$$\ln(T) = X\beta + \sigma\boldsymbol{\varepsilon}$$

where $\ln(T)$ is a natural logarithm of the time to forward citations, X is a covariate matrix, β is a coefficient vector, σ is the scale parameter, and $\boldsymbol{\varepsilon}$ is a vector of error terms. To control for unobservable heterogeneity, this study specifies the shared frailty model with a γ distribution (Gutierrez, 2002), a survival analog of the random effects model. A positive coefficient indicates a longer time interval to the first forward citation.

4. Results

Table I presents the descriptive statistics and correlations, and Table II shows the results of the AFT regressions of time to forward citations. Model 1 lists the regression results with replicator and the control variables. The coefficient of replicator is negative but not statistically significant ($\beta = -0.000616$; $p = 0.876$). Model 2 adds to Model 1 three variables

Table I.
Descriptive statistics and correlation

Variables	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Time to forward citations	2.63	1.06	1										
(2) Replicator (imitator = 0; replicator = 1)	0.26	0.44	−0.04	1									
(3) Complexity	0.36	0.28	0.05	−0.03	1								
(4) Firm specificity	0.12	0.19	0.01	0.13	−0.12	1							
(5) Technical Distance	0.35	0.37	0.05	−0.06	0.24	−0.05	1						
(6) Generality	0.30	0.27	0.08	0.02	0.45	−0.08	0.29	1					
(7) Age	4.05	2.52	0.05	−0.02	0.13	−0.07	0.05	0.09	1				
(8) Number of claims	22.07	15.80	−0.02	0.03	0.01	−0.01	−0.01	0.02	−0.06	1			
(9) Number of backward citations	13.84	20.27	0.01	0.02	0.18	−0.05	0.04	0.06	0.10	0.12	1		
(10) Number of forward citations	10.58	14.35	0.03	0.10	0.00	−0.03	−0.01	0.16	−0.06	0.13	0.09	1	
(11) Membership in triadic patent families	0.21	0.41	0.01	0.01	0.09	−0.06	0.04	0.09	0.11	0.02	0.11	0.07	1

Variables	Model 1	Model 2	Model 3
Replicator	−0.001 (0.876)	0.002 (0.598)	0.023*** (0.000)
Complexity		0.060*** (0.000)	0.066*** (0.000)
Firm specificity		0.043*** (0.000)	0.048*** (0.000)
Technical distance		0.048*** (0.000)	0.056*** (0.000)
Complexity × replicator			−0.025* (0.024)
Firm specificity × replicator			−0.015 (0.346)
Technical distance × replicator			−0.030*** (0.000)
Generality	0.030*** (0.000)	−0.010**** (0.097)	−0.010**** (0.095)
Age	0.004*** (0.000)	0.003*** (0.000)	0.003*** (0.000)
Number of claims	−0.000 (0.899)	0.000 (0.908)	0.000 (0.895)
Number of backward citations	0.000*** (0.000)	0.000** (0.005)	0.000** (0.004)
Number of forward citations	−0.002*** (0.000)	−0.002*** (0.000)	−0.002*** (0.000)
Membership in triadic patent families	−0.005 (0.178)	−0.006**** (0.079)	−0.007**** (0.074)
Cited only by replicators	0.074*** (0.000)	0.064*** (0.000)	0.065*** (0.000)
Cited only by imitators	0.017*** (0.000)	0.014*** (0.000)	0.014*** (0.000)
Year dummies (joint significance)	(0.000)***	(0.000)***	(0.000)***
Constant	1.198*** (0.000)	1.171*** (0.000)	1.165*** (0.000)
Observations	68,686	68,686	68,686
AIC	72,699.942	72,378.657	72,361.907
χ^2	6,661.454	6,988.739	7,011.489

Notes: p-values in parentheses. $*p < 0.05$; $**p < 0.01$; $***p < 0.001$; $****p < 0.1$ (two-tailed tests)

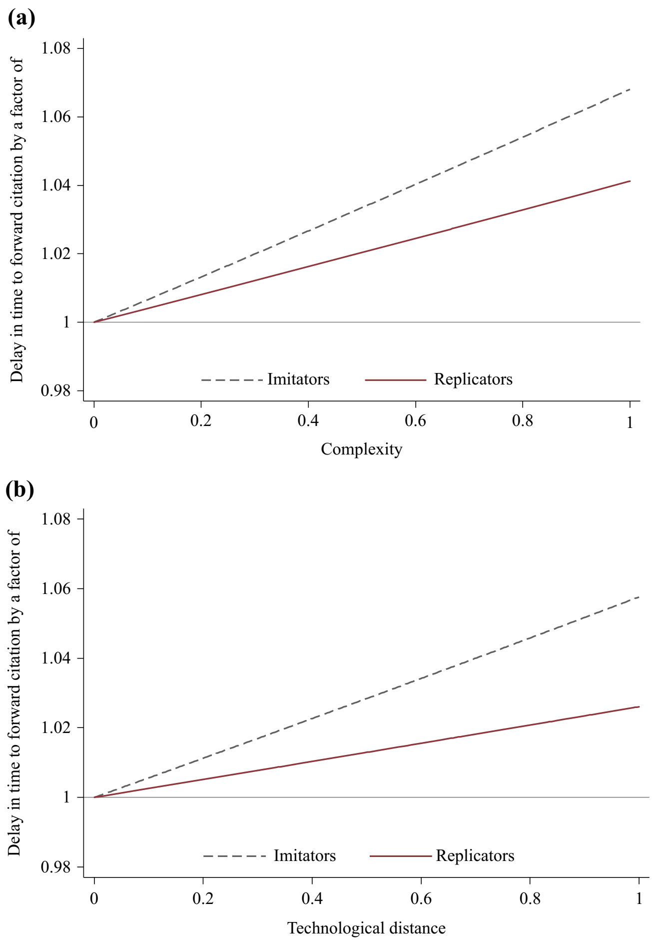
Table II. Accelerated failure-time regression results for time to forward citations

capturing complexity, firm specificity, and technological distance. Even after controlling for these knowledge characteristics, the coefficient of replicator in Model 2 is not statistically significant ($\beta = 0.00208$; $p = 0.598$). However, the coefficients of complexity ($\beta = 0.0600$; $p < 0.001$), firm specificity ($\beta = 0.0434$; $p < 0.001$), and technological distance ($\beta = 0.0482$; $p < 0.001$) are positive and statistically significant.

Model 3 shows the results of the hypotheses tests. The coefficient of the interaction between replicator and complexity is negative and statistically significant ($\beta = -0.0255$; $p = 0.024$). *H1* is thus supported. However, the coefficient of the interaction term for firm specificity is negative but not significant ($\beta = -0.0146$; $p = 0.346$). *H2* is not supported. The coefficient of the interaction between replicator and technological distance is negative and statistically significant ($\beta = -0.0303$; $p < 0.001$). *H3* is thus supported.

The support for *H1* and *H3* underscores the complementarity between organizational boundaries and knowledge characteristics in mitigating the difficulties associated with knowledge transfer. Figure 1 illustrates the changing impact on the delay in time to forward citations of complexity and technological distance between imitators and replicators. Panels (a) and (b) in Figure 1 show that, although complexity and technological distance delay knowledge transfer on average, replicators are in an advantageous position to mitigate this delay.

Given the need for a joint consideration of knowledge characteristics and organizational boundaries when explaining knowledge replication-imitation differentials, this study conducts a *post hoc* analysis to investigate the unsupported *H2* concerning the insignificant interaction between firm specificity and replicator. Given a routine-based and history-dependent search process (Levitt and March, 1988), high-firm specificity implies the existence of an organizational routine developed for exploitation rather than exploration (March, 1991). We therefore examine the potential moderating effect of technological distance on the relationship between firm specificity and replicator, considering the technology-intensive nature of the empirical context. Table III presents the results of the three-way interaction (Firm specificity × Technological distance × Replicator). The coefficient of this interaction



Notes: (a) Complexity; (b) technological distance

Figure 1.
Changing impacts on delay in time to forward citations across imitators and replicators

term is positive and statistically significant, whereas the coefficient of Firm specificity × Replicator is negative and statistically significant. Figure 2 illustrates the moderating effect of technological distance: the negative interaction effect of firm specificity and replicator on time to forward citations at a low level of technological distance turns positive at a high level of technological distance. When technological distance is low, replicators can reduce the delay to forward citations (see Panel (a) of Figure 2), whereas more time is required to replicate than to imitate when technological distance is substantial (Panel (b)). Panel (c) illustrates how the marginal effects of firm specificity on time to forward citations change for different values of technological distance. The three-dimensional graph shows that the plane for imitators is flatter than that for replicators.

Figure 2 demonstrates that replicators with high-firm specificity can enjoy organizational advantages when implementing exploitation into technologically proximate spaces. However, the same replicators would struggle to explore technologically distant spaces because their high-firm specificity would function as an

Table III. Accelerated failure-time regression results for time to forward citation (*post hoc* analysis)

Variables	Model 1
Replicator	0.027*** (0.000)
Complexity	0.066*** (0.000)
Firm specificity	0.054*** (0.000)
Technical distance	0.058*** (0.000)
Complexity × replicator	−0.026* (0.022)
Firm specificity × replicator	−0.041* (0.042)
Technical distance × replicator	−0.042*** (0.000)
Firm specificity × technical distance	−0.018 (0.452)
Firm specificity × technical distance × replicator	0.087* (0.040)
Generality	−0.010**** (0.095)
Age	0.003*** (0.000)
Number of claims	0.000 (0.891)
Number of backward citations	0.000** (0.004)
Number of forward citations	−0.002*** (0.000)
Membership in triadic patent families	−0.006**** (0.076)
Cited only by replicators	0.065*** (0.000)
Cited only by imitators	0.014*** (0.000)
Year dummies (joint significance)	(0.000)***
Constant	1.164*** (0.000)
Observations	68,686
AIC	72,361.417
χ^2	7,015.978

Notes: p-values in parentheses. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.1$ (two-tailed tests)

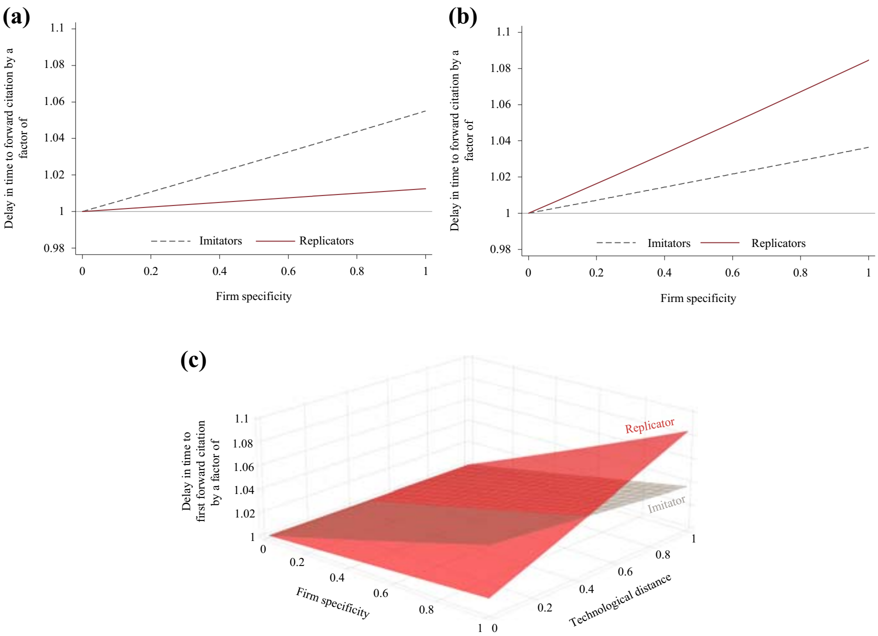


Figure 2. Moderating effects of technological distance on the relationship between firm specificity and replicator

Notes: (a) Low technological distance (10 percent); (b) high technological distance (10 percent); (c) changing marginal effects of firm specificity organizational inertia (Benner and Tushman, 2002). Firm-specific routines and language developed to facilitate knowledge transfer within a firm could make it more difficult for other firms to imitate (March and Simon, 1958). However, the *post hoc* analysis suggests that firm specificity can be a double-edged sword that can also limit replicators' search scope. These empirical findings provide additional support for the main thesis of the current study that organizational advantage depends on knowledge characteristics.

4.1 Robustness checks

We conduct multiple checks for the robustness of the empirical findings. First, seven-year window specifications for the dependent variable (i.e. time to forward citations) yield consistent results. Second, we find consistent results when measuring the dependent variable as a mean of time to forward citations. Finally, technological distance measured as a mean distance also supports the hypotheses.

5. Discussion

This study examines a theoretical model of the antecedents of replication-imitation speed differentials to assess whether knowledge characteristics influence the relationship between organizational boundaries and knowledge transfer speed. It investigates whether organizational advantage may work to delay the imitation of even highly codified knowledge embodied in a patent. It answers the research question by comparing speeds between replicator and imitator patent citation activity.

The empirical results reveal that replicators are no faster than imitators are when knowledge characteristics are controlled. The statistically insignificant coefficients of replicator in Models 1 and 2 of Table II underscore that being inside an organizational boundary alone may not provide any advantage. In addition, the coefficient of replicator in Model 3 is positive and statistically significant, implying that replication takes longer than imitation when the target knowledge has low levels of complexity, firm specificity, and technological distance. When these levels are all equal to 0, it takes around 2.30 percent ($=(\exp(0.0227)-1)\times 100$) more time for replication than for imitation. However, when knowledge is more complex or technologically distant, replicators seem to have an advantage over imitators. The statistically significant interaction effects between organizational boundaries and two of the knowledge characteristics suggest that organizational advantage in knowledge transfer is knowledge characteristic-specific rather than general. Therefore, a joint consideration of knowledge characteristics and organizational boundaries is required to explain knowledge replication-imitation differentials.

A patent's highly codified and public nature makes it vulnerable to imitation. Being an insider does not seem to offer replicators an advantage in knowledge transfer speed over imitators. However, the empirical results indicate that imitation can be delayed more than replication, allowing replicators to take advantage of the time differential. Therefore, organizational advantage may be contingent upon certain conditions, suggesting that certain characteristics need to be designed into a patent from the development stage. This seemingly intuitive finding has been discussed only conceptually (King, 2007) because studies have failed to analyze the same set of antecedents of replication and imitation. Most studies have not directly compared the difference between the speeds of replication and imitation.

The empirical results support the view that a patent discloses the major portion of know-what but little know-why or know-how, which leads to stickiness in knowledge transfer (Von Hippel, 1994). When knowledge is more complex or distant, no meaningful speed gap between replicators and imitators may appear in understanding know-what. However, replicators can understand know-why and know-how faster than imitators can.

The context in which knowledge is manipulated is important. Although patenting entails the risk of disclosing their relevant characteristics, the complexity of some patents requires major adaptation (Lichtenthaler, 2016).

Firms need to choose between integrating knowledge from distant knowledge domains or familiar domains. The expansion of search scope can enhance a firm's problem-solving capabilities (Katila and Ahuja, 2002). When developing new patents, firms should therefore strive to incorporate diverse knowledge originating from distant knowledge domains.

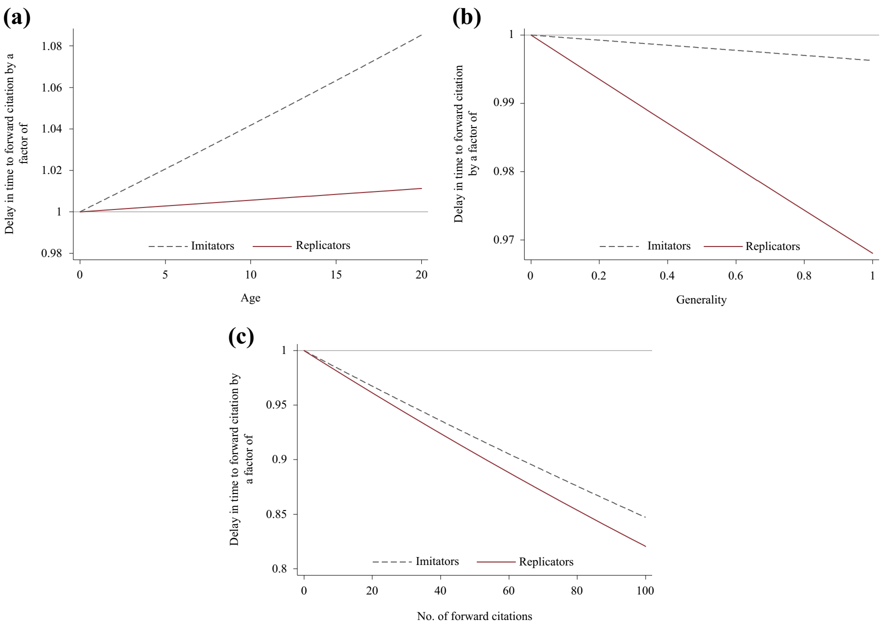
Firm specificity, measured as the ratio of self-citations to the total number of patents in backward citations of a focal patent, may be the most viable defense against imitation, but it works only for replicators' exploitation and may restrain their exploration. The empirical findings suggest that firms need to carry out searches that go beyond firm-specific knowledge. Excessive self-citations may trap the replicator in a local search.

This study conducts an additional investigation to illuminate the implications of the interaction between knowledge characteristics and organizational boundaries: the changing marginal effect of knowledge age, generality, and quality across the organizational boundary (Figure 3 and Table IV). First, old knowledge takes longer to flow (Model 1). However, Model 2 shows that replicators can substantially expedite the time to use old knowledge. Second, general knowledge seems to flow faster, as shown in Model 1; however, Model 2 shows that this is largely due to the benefits replicators enjoy, since the time reduction is not statistically significant for imitators. Finally, high-quality knowledge flows faster (Model 1), but replicators can further expedite a faster flow (Model 2).

6. Conclusion

6.1 Research and managerial implications

This study empirically investigates the knowledge replication-imitation link, a significant subject in the strategic management literature (Kogut and Zander, 1992). The characteristics



Notes: (a) Age; (b) generality; (c) no. of forward citations

Figure 3.
Changing impacts of knowledge age, generality, and quality across imitators and replicators

Table IV. Accelerated failure-time regression results for time to forward citations (additional analysis)

Variables	Model 1	Model 2
Replicator	0.002 (0.598)	0.030*** (0.000)
Age	0.003*** (0.000)	0.004*** (0.000)
Generality	−0.010**** (0.097)	−0.004 (0.568)
Number of forward citations	−0.002*** (0.000)	−0.002*** (0.000)
Age × replicator		−0.004** (0.005)
Generality × replicator		−0.029* (0.015)
Number of forward citations × replicator		−0.000**** (0.091)
Complexity	0.060*** (0.000)	0.061*** (0.000)
Firm specificity	0.043*** (0.000)	0.043*** (0.000)
Technical distance	0.048*** (0.000)	0.048*** (0.000)
Number of claims	0.000 (0.908)	0.000 (0.905)
Number of backward citations	0.000** (0.005)	0.000** (0.004)
Membership in triadic patent families	−0.006**** (0.079)	−0.006 (0.094)
Cited only by replicators	0.064*** (0.000)	0.057*** (0.000)
Cited only by imitators	0.014*** (0.000)	0.015*** (0.000)
Year dummies (joint significance)	(0.000)***	(0.000)***
Constant	1.171*** (0.000)	1.163*** (0.000)
Observations	68,686	68,686
AIC	72,378.657	72,365.754
χ^2	6,988.739	7,007.642

Notes: *p*-values in parentheses. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$; $****p < 0.1$ (two-tailed tests)

of the sample firms' patents are found to influence replication and imitation in the same direction. However, patents with certain characteristics, such as complexity and technological distance, work in replicators' favor. Complex knowledge is created by combining knowledge in diverse technological components and distant knowledge with different knowledge bases. These knowledge characteristics reduce imitation speed by increasing knowledge stickiness and strengthening the private aspect of knowledge. However, they also hurt internal replication. Thus, this study suggests that no protection against imitation is perfect, especially for highly codified knowledge such as patents. second-best alternative may be required, sacrificing replication speed somewhat but delaying imitation even more.

Second, consistent with the knowledge-based view, this study shows the value of the private aspects of knowledge. Although a patent discloses the major proportion of know-what, a patent's know-why, and know-how can lead to stickiness in knowledge transfer. The complementarity of the private and public components of knowledge may compromise imitators' ability to imitate. Future research should investigate the ways of strengthening the private aspect of codified knowledge by making it contain more know-how as well as know-what.

Finally, contrary to most studies' focus on the effectiveness of knowledge transfer, this study addresses the efficiency of knowledge transfer, highlighting that knowledge transfer speed can be critical in a competitive environment. In a dynamic context, a firm's ability to increase its knowledge transfer speed can enhance performance by continuously creating advantage over imitators. Future studies could employ our methodological approach to investigate knowledge transfer speed.

Several practical implications are suggested by this study. It provides insights into the management of technology in a codified form to increase the speed of replication rather than imitation. Its findings imply that practitioners must recognize the importance of the private aspect of knowledge to gain sustained competitive advantage. Therefore, firms and inventors need to develop new technology with more components from diverse and distant technological domains. For example, when a new chemical compound is created through a combination of several ingredients, the patent would describe the range of quantity instead of giving the exact amount required; likewise, a patent about the design of a product would not describe all the parts and components but instead place a claim on the entire product. Complexity can be increased as more elements are combined[4].

For inventors to generate innovative ideas through diverse knowledge searches within the firm, firms should pay attention to the appropriate organizational environments. Certain knowledge search and sharing mechanisms can be implemented to expand the search space. For example, centralized R&D activities may produce a work environment that more readily recognizes the value of a business unit's technologies for other businesses within the same firm (Fosfuri and Tribó, 2008). Other mechanisms include expanding access to information by allowing firm members to tap into databases containing technical knowledge, an open floor plan, and meetings open to employees, allowing them to exchange opinions and acquire insights into current product development (Nonaka and Takeuchi, 1995). For example, the coating technology of floppy disks can be incorporated with the surfactant technology of the soap division, a distant knowledge domain residing in the same firm (Rosenkopf and Nerkar, 2001). Competitors trying to imitate such knowledge, confined to the disk business, would find it difficult to understand the context of the patent. In this way, a firm can increase a patent's complexity and knowledge distance, which may enable replicators to enjoy lead time advantages over imitators (see Footnote 4).

6.2 Limitations and future research directions

First, given the study's focus on the electric digital data processing industry, these empirical findings may not be generalizable to other industries. Common knowledge and competency levels across an industry influence imitation speed (Eisenhardt and Santos, 2002). Moreover, competitive pressure increases firm efficiency in knowledge transfer. Thus, comparative studies across different industries would be worthwhile.

Second, because of the nature of a patent as a unit of analysis, this study cannot consider replicators' and imitators' characteristics such as capabilities and strategies with respect to the absorption of new knowledge. Knowledge resides at multiple levels: firm, research team, individual inventors, and routines (Hoetker and Agarwal, 2007). This research does not capture knowledge at all the relevant levels. Nonetheless, we believe that the patent is appropriate for capturing and comparing the moves of individual subsequent knowledge owners (replicators and imitators). In addition, by showing that even patent-level knowledge may be protected from imitation, this study opens the door for further investigation into more aggregated levels of knowledge replication and imitation. The possibility of broadening the gap between replication and imitation is expected to increase as future studies focus on higher-level knowledge.

Third, endogenous results are a possibility because of the presence of decision-makers and decision outcomes in the same analytical model. The time to forward citations is influenced by not only the characteristics of knowledge but also other factors, such as a firm's intention to delay patent filing to prevent its technology from being disclosed.

Finally, knowledge transfer can be facilitated by employee turnover (Eisenhardt and Santos, 2002), which is not addressed in this study. Examining employee turnover and its resulting moderation of knowledge characteristics and transfer speed would be a valuable subject in the fields of knowledge management and social capital.

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Notes

1. Four parties are involved in the replication-imitation process. The first is the organizational unit (i.e., department, division, business unit) that houses the knowledge that becomes the target of replication or imitation. The second party is another unit within the same organization that wants to learn and replicate the target knowledge (replicator). The third party is the organization to which the source unit and replicators belong. The last party is an outside organization that wants to imitate the target knowledge (imitator).
2. The number of observations (68,686) is greater than that of patents (52,723). Of the 52,723 patents, 51,074 have at least one citation by other assignees (imitators), and 17,612 have at least one citation by the same assignee (replicator). This study obtains 68,686 observations by adding these two numbers. Since there are 15,963 duplicate counts (i.e. cited by both types of assignees), subtracting them from 68,686 results in 52,723.
3. For instance, if a patent applied for in 1996 has three forward citations by replicators in 1997, 1998, and 1999, then time to forward citations for replicators is calculated as 2. Likewise, if the patent has three forward citations by imitators in 1998, 1999, and 2000, then time to forward citations for imitators is calculated as 3.
4. These examples are based on the interviews with two patent inventors and one corporate patent lawyer at a major global electronics company and one independent patent lawyer.

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