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The Design Sourcing Choice and Technological Performance in the Upscale and Downscale Markets of an Architectural Innovation

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ABSTRACT

In this study, we investigate the performance impacts of design sourcing choices in addressing an architectural innovation from its originating market to subsequent markets. We maintain that the effects of design internalization and externalization on the technological performance of firms' products may vary across the originating and subsequent markets with different requisite technological demands due to the dynamics of knowledge spillovers and knowledge exchange hazards in those markets. We hypothesize that design internalization is likely to outperform design externalization when facing an architectural innovation in a subsequent upscale market with a higher technological performance requisite than in the originating market. The case is then reverse in a subsequent downscale market with a lower technological performance requisite. We test our hypotheses in the empirical contexts of the U.S. bicycle markets in which the index gear-shifting technology (i.e., an architectural innovation) originated in the road bicycle market in 1985 and subsequently traversed to the mountain bicycle market (i.e., an upscale market) in 1987 and the city bicycle market (i.e., a downscale market) in 1988. The results are largely in line with our hypotheses. The contributions of our study to the current literature as well as its managerial implications are also discussed.

- Managers can strategically leverage an architectural innovation that occurs in one market to improve a product in another market.
- When a subsequent market of the architectural innovation is technologically upscale, managers should keep design activities of the product in-house to better manage the knowledge gap between the markets and the needed additional technological investments.
- Conversely, in a subsequent technologically downscale market, the knowledge spillovers between the markets facilitate the technological saturation and the proliferation of capable suppliers, making outsourcing the design activities more attractive to managers.

Key Words: Architectural Innovation, Design Sourcing Choice, Knowledge Spillover Effects, Knowledge Exchange Hazards, Technologically Upscale and Downscale Markets

INTRODUCTION

Innovative changes in product architecture can affect firms' product performance, market standing, survival chance, and even industry structure (Baldwin & Clark, 2000; Christensen, Verlinden, & Westerman, 2002; Fine, 1998). Such changes, characterized by alterations in how a product's components are linked together while keeping the core design concepts of the components largely intact, are referred to as architectural innovations (Henderson & Clark, 1990). Adopting and implementing an architectural innovation often calls for reconfigurations of the existing product components and their linkages, which can result in unforeseeable interdependencies among parties involved in the design and development of various product components (Henderson & Clark, 1990). Previous research has thus suggested that design internalization (i.e., maintaining design activities in-house) is more advantageous than design externalization (i.e., outsourcing design activities to external suppliers) for architectural innovation performance (Afuah, 2001; Kapoor & Adner, 2012; Park & Ro, 2011, 2013). This is mainly because the former enables firms to reconfigure components in a more timely and optimal manner based on integrative and cooperative operations among members within the organization (Salvador & Villena, 2013).

While this literature has advanced our understanding of design sourcing for architectural innovations, it is based largely on research studies limited within product markets where architectural innovations originate. However, the phenomenon of innovations traversing from one product market to another is quite common and relevant to managers who direct their firm's design activities and sourcing strategies across different markets. Consider a historical case of the architectural innovation for four-wheel-drive vehicles in the U.S. automotive industry. This innovation first established itself in the military and industrial markets in the 1930s and subsequently entered the general consumer market in 1945 (Allen, 2016; Nunney, 2012). In the context of such innovation diffusion across markets, it is not clear whether design internalization is a preferred sourcing choice when an architectural innovation traverses from its origin to products targeting different markets. Potential spillovers (Jaffe, 1986; Mansfield, 1985) of the associated architectural knowledge can occur across the markets and facilitate learning among industry players. The uncertainty surrounding product and component designs can thus be reduced, making design internalization a less attractive sourcing choice. However, the characteristic differences between markets (Argyres & Bigelow, 2010) may also present distinct challenges that can render the knowledge acquired from such spillovers incomplete or less valuable in subsequent markets. Design internalization can thus become a more preferred sourcing choice. Previous research has not addressed the dynamics of design sourcing choices and performance implications in this particular context, leaving a gap in the literature for further research.

To fill that gap, this study examines the performance impact of design internalization in the context of an architectural innovation traversing from its originating market to other subsequent markets. We contend that the effectiveness of design sourcing choices in this context is influenced by the requisite technological performance of the product in the subsequent market compared to that in the originating market. A subsequent market is considered *technologically upscale* or *technologically downscale* when the requisite technological performance in the subsequent market is respectively *higher* or *lower* than that in the originating market. We then ask the following research questions: (1) In the subsequent technologically upscale market, which design sourcing choice provides greater technological performance advantages? (2) In the subsequent technologically downscale market, which design sourcing choice provides greater technological performance advantages? Finally, (3) do the performance impacts of design internalization in subsequent markets differ from those in the originating market?

To investigate these questions, we draw our arguments from the concepts of *knowledge spillovers* and *knowledge exchange hazards*. A knowledge spillover occurs when knowledge flows from one party (the originator) to another (the recipient) (Jaffe, 1986), thus creating inexpensive learning and innovation opportunities for the recipient party (Yang, Phelps, & Steensma, 2010). Knowledge exchange hazards are referred to as opportunistic behaviors that involve withholding or distorting important knowledge or shirking obligations and promises by exploiting mutual knowledge dependency (Nickerson & Zenger, 2004). Our core argument is that the reusability and value of the original architectural knowledge acquired through knowledge spillovers may vary in the subsequent technologically upscale and downscale markets. Accordingly, the recipient firms in these subsequent markets may differ in terms of their need for additional specific investments in design activities. They face different levels of complexity and uncertainty in coordinating and matching the design activities of interdependent components and their interfaces (Salvador & Madiedo, 2021), as well as different degrees of supplier opportunism that may potentially arise (Nickerson & Zenger, 2004). Under these different circumstances across the markets, the impacts of design sourcing choices on the technological performance of the products may vary as well.

For the empirical examination in this study, we use the U.S. bicycle industry with a focus on index gear-shifting technology as a research context. The index gear-shifting technology is an architectural innovation that originated in the road bicycle market in 1985 (Park, Ro, & Kim, 2018) and subsequently moved to the mountain bicycle market in 1987 and to the city bicycle market in 1988. Figures 1a and 1b show the mountain and city bicycle markets as the subsequent technologically upscale and downscale markets of the architectural innovation, respectively. This empirical setting is thus suitable for the research questions of this study.

This study advances the make-buy and sourcing literature in two significant ways. First, this study contributes to the debate on the performance impact of make-buy sourcing decisions in dealing with innovations for the make (Monteverde, 1995; Williamson, 1985) and for the buy (Balakrishnan & Wernerfelt, 1986; Powell, Koput, & Smith-Doerr, 1996) choices. Going beyond previous research that seems to treat the advent of an architectural innovation in a given market as a discrete event, this study uniquely examines sourcing choices in both the originating and the subsequent markets of an architectural innovation and conceptualizes them as interrelated events through knowledge spillovers between them. By doing so, this study suggests that the technological performance of firms' product offerings can be achieved through either of the two sourcing choices depending on the requisite performance demands in the originating and subsequent markets. Second, by deepening our understanding of the issues of design sourcing, architectural innovation, and market technological requirements, this study offers the strategic sourcing literature (Afuah, 2001; Kapoor & Adner, 2012; Park & Ro, 2011) more dynamic insights into the role of market technological requirements in determining appropriate sourcing choices.

----- Insert Figures 1a and 1b around here -----

LITERATURE REVIEW

Architectural Innovations and Component Sourcing

Architectural innovations involve changing the linkages between constituent product components while leaving the core design concepts of the components intact (Henderson and Clark, 1990). To invent new component linkages for an architectural innovation, working divisions in an organization need to create new communication channels, operating procedures, and routines (Nelson & Winter, 1982). Due to these hurdles, firms often find it difficult to successfully adopt an architectural innovation, and some of them end up exiting the product market even in the face of a seemingly simple architectural innovation (Christensen, Suarez, & Utterback, 1998).

Given the potentially large impact of architectural innovations on firms' survival, scholars have emphasized the importance of appropriate sourcing decisions (Park & Tangpong, 2021), and suggested that internalized component sourcing provides performance advantages over externalized component sourcing when addressing architectural innovations (Afuah, 2001; Kapoor & Adner, 2012; Park & Ro, 2013). A major argument for internalized component sourcing is to mitigate knowledge exchange hazards, which potentially arise when dealing with coordination issues with external vendors in response to a new architectural innovation (Nickerson & Zenger, 2004; Wolter & Veloso, 2008). To successfully address architectural innovations, firms need to re-examine and reconfigure the linkages among components, thus requiring greater coordination with external suppliers if those components are outsourced. Such high coordination tends to increase relationship-specific investments with the suppliers (Williamson, 1985), thus putting suppliers in positions where they can behave opportunistically (e.g., shirking, suppressing or altering important information, or neglecting obligations by exploiting mutual dependencies) (Nickerson & Zenger, 2004). These potential acts of supplier opportunism may increase the burden for sourcing coordination.

Along that line of argument, Kapoor and Adner's work (2012) based on the DRAM market has suggested that architectural innovations require firms to tightly coordinate the integration of components and manage their interdependence to accommodate new types of linkages. The externalized component-sourcing choice is relatively ineffective in dealing with the high coordination required for designing new linkages, thus making firms more susceptible to high exchange hazards (i.e., suppliers' opportunistic behaviors) in their sourcing relationships (Nickerson & Zenger, 2004; Williamson, 1985). In contrast, the internalized component-sourcing choice allows greater coordination and enables firms to limit the potential opportunism from suppliers. In addition, the internalized component-sourcing choice is inherently better at creating dedicated communication codes and channels that facilitate the development of new component linkages (Monteverde, 1995; Tenhiälä & Salvador, 2014).

Along a similar line of logic, Park and Ro (2013) studied the road bicycle market and suggested that when the dominant product architecture changed from a modular to an integral form via an *architectural* innovation, firms pursuing a make choice would likely show better technological and financial performance than firms pursuing a buy choice. Likewise, Afuah (2001) showed that in response to the technological change from a CISC to a RISC architecture in microprocessor design (i.e., an architectural innovation), the vertical integration of suppliers' components was more effective in dealing with the architectural change due to the high degree of coordination needed among the components. Lastly, Park and Tangpong (2021) investigated the performance impact of make-buy sourcing choices across an architectural innovation life cycle in the road bicycle market. They highlighted that firms, starting with a buy sourcing choice and then switching to a make sourcing choice when key market-winner features were known, could obtain performance advantage and enhance their survival during the market shakeout period.

Strategic Design Sourcing Choice and Architectural Innovation Performance

At a finer-grained level of observation, some scholars have compartmentalized design sourcing from production sourcing and examined the in-house design of outsourced components (Park & Ro, 2011; Ulrich & Ellison, 2005).[3] Ulrich and Ellison (2005) studied the bicycle market and pointed at the importance of dividing internalized sourcing along two functions: 'design' internalization and 'production' internalization. Since much of the existing literature does not clearly differentiate design internalization from production internalization, the sourcing decision that internalizes design but externalizes production is often considered an externalized sourcing decision and has been less studied to date.

A few researchers such as Park and Ro (2011) have extended Ulrich and Ellison's (2005) work and maintained that design internalization allows firms to enjoy the advantages of the make choice, but also complements the weaknesses of a pure buy choice in dealing with architectural innovations. By internalizing the design of outsourced components, firms can provide timely design

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[3] Another literature stream revolves around the role of a long-term relationship with a supplier. Through a long-term relationship, a firm and its suppliers can build up mutual trusts (Gulati, 1995), reduce suppliers' potential opportunism, and facilitate the creation of new linkages in dealing with architectural innovations (Hoetker, 2005). We include long-term relationship as a control variable in our study.

specifications that component suppliers should follow (Salvador & Villena, 2013). At the same time, based on this strong connection with suppliers, the firm can efficiently monitor the supplying partners' work progress and task performance, and eventually reduce exchange hazards and opportunism from suppliers during production (Tiwana & Keil, 2007). The empirical findings overall suggest that a sourcing choice that internalizes design (while externalizing production) tends to outperform a sourcing choice that externalizes both design and production, and attains comparable performance to a sourcing choice that internalizes both design and production (Park & Ro, 2011).

In addition, Park et al. (2018) reported that, for firms adopting an architectural innovation that has emerged in their market, design internalization may have a positive impact on their performance *only after* the emergence of a dominant design. In the early period of a new architectural innovation, the firms' primary concern is how to efficiently identify and acquire new knowledge required by the emerging innovation (Henderson & Clark 1990, pp.16-18). However, design internalization will confine their search for new knowledge within the boundaries of their own established knowledge base (Tiwana & Keil, 2007), thus undermining their performance during this early period (Park et al., 2018). While previous studies on this topic frequently highlight the positive role of design internalization with regards to performance, recent work by Park et al. (2018) suggests the possibility that design internalization can lead to negative (or positive) performance effects under different contexts.

This study builds on previous research regarding the impact of design sourcing choices and their importance in varying contexts (e.g., Park & Ro, 2011; Ulrich & Ellison, 2005; Park et al., 2018). We aim to advance this literature stream by examining the positive or negative role of design internalization while considering the potential knowledge spillover[4] across markets (i.e., from the

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[4] Previous research on knowledge spillover has focused largely on the unintentional flows of knowledge from one firm to another in the context of horizontal alliances (e.g., Jaffe, 1986; Mansfield 1985; Yang et al., 2010). In this study, we apply the concept of knowledge spillover to the flows of knowledge between markets in our theoretical development – specifically from the originating market of an architectural innovation to its subsequent markets.

originating market to subsequent markets) with different levels of requisite technological performance. An innovation that originated in one market is known to subsequently traverse to other markets (Scarrà & Piccaluga, 2021; Zhao, Jiang, & Wang, 2019). Following this obervation, an architectural innovation can subsequently diffuse to products targeting other markets that differ from the one in which it originated. In such a context, it is not clear whether internalization or externalization is the best design sourcing choice. On one hand, the potential spillover of the associated architectual knowledge to industry players in subsequent markets can facilitate the imitations of ideas from an innovator (Mansfield, 1985), promulgate new knowledge sharing for innovations from the market (Spencer, 2003), and reduce technological and market uncertainty (Agarwal, Audretsch, & Sarkar, 2007), thus making design internalizaiton a less attractive choice. On the other hand, target markets may have characteristics distinct from the originating market of the architectural innovation, limiting the value and applicability of the knowledge accrued from the spillover (Yang et al., 2010) and making design internalization a more attractive choice. These considerations have not been considered in the current literature. To address this gap, our study examined the effectiveness of design sourcing choices in the context of an architectural innovation traversing from its originating market to subsequent markets with different technlogical performance requisites.

RESEARCH CONTEXT

Architectural Innovation – Index Shifting Technology

Structurally, the bicycle is composed of not just elementary components but a nested hierarchy of subsystems (Murmann & Frenken, 2006) including the wheels, frame, brakes, and gear-shifting system as illustrated in Figure 2 (Galvin & Morkel, 2001). For the research context of our current study, we focus on the bicycle gear-shifting set, which comprises four key components: the chain, freewheel, shifter, and derailleur (see Figures 2 and 3). Historically, for several decades, bicycle riders tolerated clumsy and inaccurate gear-shifting systems. Before index shifting, the movements of the steel wire actuating on the derailleur were continuous and subject to lever adjustment by the riders. Changing gears on a bicycle was often a stressful and subjective experience, frequently resulting in mis-shifting. Then in 1985, Shimano Inc. introduced its index shifting technology to the road bicycle market. This new technology discretized the movements of the steel wire actuating on the derailleur and allowed bicyclists to change gears with the simple push of a button. Index shifting technology became extremely popular quickly after its introduction.

Index shifting was deemed an architectural innovation (Bigelow, Nickerson, & Park, 2019; Fixson & Park, 2008; Park et al., 2018) which significantly altered how gear shifting was performed and how the key components were linked together. With the previous continuous non-indexed gear-shifting set, shifting performance was highly dependent upon a riders' skill, experience, and subjective feel. The product architecture of the continuous non-indexed gear-shifting set was modular and standardized with a high interchangeability of components from different manufacturers (*Bicycling*, March. 1980, pp.80-83).[5] The need for coordination and interaction among different component design activities was thus minimal.

However, with the new index shifting innovation, gear-shifting performance would depend far less on a rider's skill but more on the intricate design of the index gear-shifting set, which would automate and simplify gear-shifting. The intricate design of the index gear-shifting set led to dramatic changes in component linkages (*Bicycling*, Jan./Feb. 1988, pp.108-128). First, the linkage between the derailleur and the freewheel (two major components of the gear-shifting system) became a critical factor for shifting performance after the introduction of index shifting (Link A in

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[5] Before 1985, Campagnolo's continuous non-index gear-shifting sets were known to have the best quality in the market. Campagnolo's product architecture became the *de facto* standard and was adopted by many firms, allowing high interchangeability between components across different manufacturers. It was not uncommon for bicycle manufacturers to mix-and-match various gear-shifting components from different companies during that time.

Figure 3). Increased sliding friction and mis-shifting could occur as the chain was pulled onto the freewheel if this linkage (newly named the "chain gap") (see Figure 3) was too wide or too narrow (*Bicycling*, Jan./Feb. 1988, pp.108-128). The term "chain gap" was invented to describe this newly designed linkage between the derailleur and freewheel components that was critical to the gear-shifting performance within the index shifting system. This term did not exist before 1985 because it was not a critical feature within the continuous non-index gear-shifting system.

Second, the linkage between the shifter and derailleur (i.e., the shifter cable) needed to be redesigned (Link B in Figure 3) after the derailleur and freewheel were redesigned for index shifting. The length and tension of the cable connecting the derailleur and the shifter had to be readjusted (*Bicycling,* Mar./1987, p.38). Finally, the chain itself needed to be redesigned to assure shifting precision. The chain redesign proceeded along the dimensions of the redesigned derailleur and freewheel (Link C in Figure 3). Optimal index gear-shifting performance required a newly designed chain to fit the optimized chain gap. In short, these components would need to be designed to mutually fit one another for optimal gear-shifting performance. A change in the design of one component would likely call for mutual adjustments in the designs of other components in the new index gear-shifting system; thus, the need for coordination and interaction among different component design activities increased substantially.

----- Insert Figures 2 and 3 around here -----

Three Bicycle Markets with Different Levels of Requisite Technological Performance

The road bicycle (RDB) market initially experienced the index shifting innovation when it was first introduced in 1985. Two years later (in 1987), this innovation was transferred to the mountain bicycle (MTB) market. MTBs were intended to be ridden across rough and rugged terrain, and MTB enthusiasts required the quick precision of index shifting systems. MTB riders typically demanded a level of shifting performance beyond that of RDB enthusiasts because RDBs were intended to be ridden across milder and less harsh surface conditions (see Figures 1a and 1b for shifting performance ranges).

In 1988, the index shifting innovation was then transferred to the city bicycle (CTB) market. CTBs were intended to be ridden across flat and paved urban environments for short, comfortable commutes and rides. They were designed to be all-purpose, practical bicycles for everyday riding and transportation – they were not built for rigorous recreation or intense competition (unlike RDBs and MTBs). Predictably, the typical shifting performance requirements of CTBs were lower than those of RDBs and MTBs (Figures 1a and 1b). The lower shifting performance requirements of CTBs versus RDBs and MTBs did *not* indicate that providing desirable shifting performance was no longer the key basis of competition for firm survival. In the CTB market, offering desirable shifting performance was still key, but the shifting performance requirements were typically lower when compared to MTBs and RDBs.

Besides the variations in shifting performance requirements, the three types of bicycles also differed technically. While the underlying shifting mechanism among the three types of bicycles was similar, each bicycle type's gear-shifting set was suited for different riding demands. Therefore, the design of the gear-shifting components and their features varied across the three bicycle markets, and the compatibility between comparable components across the three markets was rather low.[6] In addition to the incompatibility of the gear-shifting components across the different bicycle markets, the incompatibility of product lines within a single firm could also be quite high. Thus, a bicycle manufacturer producing both RDBs and MTBs could still face a high degree of component incompatibility[7] between different product lines. For instance, a freewheel used for the RDB

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[6] For instance, as explained with greater details in Footnote #10 of the *Control Variable* Section, there were eight new critical features (that were not incorporated into non-index gear-shifting sets). These were grouped into four feature sets: derailleur, freewheel, chain, and shifter. Each type of bicycle had unique combinations of these four feature sets. Thus, incompatibilities between the three types of bicycles (RDB, MTB, and CTB) were considerable.

[7] *Sutherland's Handbook for Bicycle Mechanics* contains over 700 pages of extensive illustrations and descriptions concerning the compatibility of all the bicycles' gear-shifting systems and components from the 1960s to 2005.

product line would not be compatible with the MTB product line even if both types of bicycles were produced by the same bicycle manufacturer.

Overall, the index gear-shifting systems were uniquely characterized by technological (in)compatibility and different requisite technological performance demands across the RDB, MTB, and CTB markets. These three markets together thus offer a rich opportunity to investigate our research inquiry regarding the performance impact of design sourcing choices in the context of an architectural innovation (index shifting technology) traversing from its originating market (RDB) to subsequent markets (MTB and CTB) with distinct technological performance requisites.

THEORY AND HYPOTHESES

Originating Market: Road Bicycle Gear Shifting

Index shifting innovation began in the road bicycle (RDB) gear-shifting market in 1985. As discussed in the *Literature Review* section, the creation of new component linkages within a new product architecture requires intensive knowledge coordination between a firm and its suppliers thus significantly increasing their interdependency (Nickerson & Zenger, 2004; Williamson, 1985). The empirical evidence from the road bicycle market indicates that design internalization is better for technological performance than design externalization when it allows the firm (a) to provide timelier design specifications to suppliers (Tiwana & Keil, 2007) and (b) to more effectively reduce supplier opportunism potentially arising from the high knowledge coordination and dependence (Park & Ro, 2011).

Subsequent Technologically Upscale Market: Mountain Bicycle Gear Shifting

The key features of indexed components within the new architecture did not occur in the MTB market until 1987. The two-year time gap from its initial introduction in the RDB market was arguably a period in which knowledge related to the index shifting innovation spilled over from the RDB market to the MTB market. As suggested in the knowledge spillover literature, knowledge associated with innovations can diffuse from their origins to other loci within or across industries through mediums such as industry and trade publications, conferences, trade shows, and industry associations (e.g., Baker, 1999; Bartov & Bodnar, 1994; Park, Shin, & Choi, 2020; Zajonc, 1968). Likewise, in the bicycle industry, trade magazines (such as *Bicycling* and *Bicycle Tech*) were especially popular in the 1970s-1990s and were quite technologically-oriented during that period.[8] These trade magazines provided knowledge repositories and served as vehicles through which knowledge associated with new innovations could spread to various players in different markets of the bicycle industry.[9] In addition, bicycling industry trade shows and conferences were other vehicles through which firms could both share and learn about new innovations in the market.[10] Display booths showcasing a firm's index shifting innovation were quite popular and allowed firms to study and compare various index shifting innovations.

We note that knowledge acquired from spillovers, while important, may be incomplete due to part of the knowledge potentially being tacit (Lam, 2000; Teece, 1986) or insufficient to fulfill all the technological and knowledge requirements for certain innovations of the recipient firm (Yang et al., 2010), thus creating a technological and knowledge gap. We maintain that this gap becomes wider when the knowledge recipient operates in an upscale market with a higher level of requisite technological performance than the knowledge originator's market. This is potentially because higher requisite technological performance in the upscale market may limit the reusability of the

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[8] However, since the 2000s, bicycling-related magazines no longer heavily emphasized technical explanations but rather switched to emphasize marketing through collaboration with bicycle companies (or dealers) in order to maintain revenues.

[9] For example, one key performance indicator involved the performance of various gear-shifting systems. *Bicycling* would conduct annual tests regarding the performance of different gear-shifting systems and rank them. It was not surprising that these test and performance reports heavily impacted sales. As a result, heated debates between the technical editors of trade magazines and company managers often ensued. Firms would make efforts to thoroughly explain the mechanics of their gear-shifting innovation to technical editors so that the innovative aspects of their products could be conveyed to broader groups of prospective customers.

[10] For example, Shimano's index shifting innovation was first introduced to the market at an industry trade show in December 1984. Since then, both Shimano and its rivals used trade shows to introduce their index shifting innovations annually.

original architectural knowledge. As suggested in the research on interface mismatch (Salvador & Madiedo, 2021), complex and uncertain interdependencies among component designs can occur because the interface among component designs within the original architecture may mismatch with the component design specifics needed for higher technological performance in the upscale market.

This argument can be concretely exhibited by the spillover of four key features in the indexed derailleurs (i.e., spring-loaded pivots, slant parallelogram, cage geometry, and pulley spacing) from the RDB market to the MTB market. As the four features of indexed derailleurs were adopted in the MTB markets, they needed to be substantially redesigned and upgraded to optimize shifting performance. For example, slant angles in the indexed derailleur (see Figure 3) for RDBs ranged typically from 32 to 45 degrees. The slant angles were redesigned to a range of 50 to 70 degrees when traversing into the upscale MTB market (*Bicycling*, Jan./Feb. 1988, pp.108-128). These angle changes required specific design activities and re-optimizing efforts with the other three key features to fit this augmented feature (*Bicycling,* Mar./1987, p.38). Furthermore, the change of the derailleur design led to changes of the freewheels and shifters to the extent that the freewheels and shifters for MTBs were no longer compatible (i.e., interchangeable) with the freewheels and shifters designed for RDBs (*Bicycling*, Jan./Feb. 1988, pp.108-128) (see also Figure 3). To take full advantage of the knowledge from the RDB market, the recipient firm needed to bridge this technological and knowledge gap by making additional specific investments to upgrade the acquired architectural knowledge and strengthen component designs with distinctive features to satisfy the high-level technological demand in the MTB market.

Such specific investments in architectural knowledge and distinctive design features can also lead to greater exchange hazard risks (i.e., suppliers' potential opportunistic behavior arising from high coordination issues) when the firms' distinctive design activities are outsourced to external suppliers (Argyres & Bigelow, 2010; Park & Ro, 2011). Taken together, the complex and uncertain interdependencies among component design activities and the exchange hazard risks from design-specific investments in this situation make design internalization more attractive than design externalization. Based on these arguments, we propose the following hypothesis.

> *Hypothesis 1a: In a subsequent market characterized by a high level of technological demand (i.e., the mountain bicycle market), design internalization is likely to provide greater performance than design externalization when facing an architectural innovation (i.e., index shifting technology).*

In addition, the interdependencies among component design activities and the design-specific investments that potentially lead to higher exchange hazards become substantially greater for firms in a technologically upscale market. In this context, design internalization provides greater degrees of coordination to achieve efficient design activities while meeting higher technological demands for a technologically upscale market. Accordingly, adopting design internalization is more critical to firms in the subsequent upscale market (i.e., the MTB market) than to those in the originating market (i.e., the RDB market) to achieve desirable technological performance. Therefore, we propose another hypothesis as follows.

> *Hypothesis 1b: The impact of design internalization on technological performance is likely to be greater in a subsequent market characterized by a higher level of technological demand (i.e., the mountain bicycle market) than in the market where the architectural innovation originated (i.e., the road bicycle market).*

Subsequent Technologically Downscale Market: City Bicycle Gear Shifting

The index shifting innovation was then adopted in the city bicycle (CTB) market in 1988 – approximately three years after it was introduced in the RDB market. It was during this three-year gap that the knowledge concerning index shifting innovation spilled over from the RDB market to the CTB market primarily through the previously described mediums of trade magazines and trade shows. Figures 1a and 1b show that the CTB market is considered a technologically downscale market with a lower level of requisite technological performance than the originating RDB market.

Drawing from the knowledge spillover literature (Jaffe, 1986; Mansfield, 1985), we argue that when knowledge spills over from one market to another technologically downscale market, the knowledge available through the spillover can adequately fulfill the knowledge requirements of the recipient firm's market. Thus, to take full advantage of the knowledge or innovations obtained from this downward spillover, the recipient firm is not required to invest substantially in additional knowledge development and distinctive design activities, and can still satisfy the requisite level of technological performance in its market.

This line of argument is manifested in the RDB and CTB contexts where the four key features in the indexed derailleurs (i.e., spring-loaded pivots, slant parallelogram, cage geometry, and pulley spacing) spilled over from the RDB market to the CTB market. While these four features had to be significantly modified to fit MTBs, they were adopted from RDBs into CTBs without much change. Consequently, other components in the gear-shifting system did not need to be modified for CTBs either (*Bicycling*, Jan./Feb. 1988, pp.108-128). In other words, the interdependencies among the component designs were largely confined within their established interfaces of the original architecture (Salvador & Madiedo, 2021).

We also maintain that the traversing of knowledge and innovation from a market with a higher requisite level of technological performance (i.e., the RDB market) can arguably expedite technological saturation (Agarwal et al., 2007; Agarwal, Audretsch, & Sarkar, 2010) in a technologically downscale market (i.e., the CTB market) within a given time period. Thus, after the period of such knowledge and innovation spillover, various gear-shifting manufacturers and suppliers could more readily use the available index shifting technology from the RDB market, to improve their product offerings in the downscale CTB market (Jaffe, 1986; Mansfield, 1985). In this situation, the number of capable suppliers is also proliferated, reducing the risks from knowledge exchange hazards and supplier opportunism (Williamson, 1985). In addition, potential suppliers can be pitted against one another providing a suitable quality of components when they compete for a manufacturing firm's business.

Given this competitive market situation, design internalization can be a hindrance for firms to fully use market incentives and leverage a large pool of suppliers toward their advantage. In contrast, design externalization gives bicycle manufacturing firms the latitude to select appropriate designs for their products from a range of capable suppliers. Design externalization then becomes a viable and efficient option for the firms in a technological downscale market given the knowledge and innovation spillover. Similarly, the market can become a more efficient form of governance than hierarchy when supplier opportunism is constrained as established in the transaction cost economics literature (Williamson, 1985). Based on the above arguments, we propose Hypothesis 2a as follows.

> *Hypothesis 2a: In a subsequent market characterized by a low level of technological demand (i.e., the city bicycle market), design internalization is likely to provide lower performance than design externalization when facing an architectural innovation (i.e., index shifting technology).*

In addition, with limited specific investments in distinctive design activities and technological features, firms in a technologically downscale market (i.e., the CTB market) are less likely to face knowledge exchange hazard risks arising from supplier opportunism (Argyres & Bigelow, 2010) and require less modification and coordination among design activities (Nickerson and Zenger, 2004) than those in the originating market (i.e., the RDB market). We therefore argue that design internalization would be less critical to firms facing a lower-level technological performance requirement in the subsequent downscale market than to those in the originating market. Based on this additional line of reasoning, we propose Hypothesis 2b as follows.

> *Hypothesis 2b: The impact of design internalization on technological performance is likely to be less in a subsequent market characterized by a lower level of technological demand (i.e., the city bicycle market) than in the market where the architectural innovation originated (i.e., the road bicycle market).*

METHODS

Sample and Data Collection

The data used in this study were collected from bicycle gear-shifting sets that were sold in the U.S. bicycle markets from 1985-1995. The index-shifting innovation was first introduced in the road bicycle (RDB) market in 1985, two years later in the mountain bicycle (MTB) market, and a year after that in the city bicycle (CTB) market. We performed repetitive tests for RDBs (Park et al., 2018) with a total of 284 observations for RDBs (i.e., 119 for design internalization and 165 for design externalization). We also have 195 observations for MTBs (105 for design internalization and 90 for design externalization) and 184 observations for CTBs (65 for design internalization and 119 for design externalization).

Major sources of information regarding the bicycle industry over this period of our study included trade publications and magazines. Bicycling enthusiasts and technicians frequently referred to these periodicals. Trade periodicals often provided information related to various bicycle models, component prices, and bicycle performance metrics. They also provided technical information pertaining to shifting mechanisms, component compatibility, instructions regarding the assembly of components, etc. One of the most prevalent trade publications in this industry was *Bicycling*, which developed a proprietary database, Super Spec, that amassed information about different bicycle models, types of components, and their manufacturers. We obtained a copy of this database from previous technical editors of *Bicycling*, and used it as a primary data source in measuring the majority of the variables in our study. We supplemented the Super Spec database with *Bicycling*'s (semi)annual report, which provided information about gear-shifting performance every year as *Bicycling* conducted the testing of shifting performance with their own facilities. Finally, we used *Sutherland's Handbook for Bicycle Mechanics (6th ed.)* as another supplemental data source. It contained more than 700 pages of wide-ranging illustrations and descriptions in addition to detailed figures for various components and their assembly. This handbook also provided details regarding different components and their compatibilities for various bicycle models between 1960 to 2005.

Dependent Variables

We operationalized *technological performance*, our dependent variable, based on gear-shifting performance. We selected *Shifting Speed*$_{fts}$ and *Shifting Smoothness*$_{fts}$ as variables to measure shifting performance. These measures have also been used in previous research (e.g., Park et al., 2018) and were based on the shifting performance data from *Bicycling*'s (semi)annual report. *Shifting Speed*$_{fts}$ gauged how rapidly a gear-shifting set s produced by a firm f at time t could change gears. *Bicycling* used specialized equipment to rigorously examine gear-shifting systems every year. These specialized tools randomly shifted gears for each individual bicycle model several times within a defined time duration. Each gear-shifting set was examined across a series of 16 shifts in *Bicycling's* test. The shifting speed was evaluated based on early and late gear change events. Early-shifting derailleurs required little lever force when changing gears, but a late-shifting derailleur would often miss a gear. Faster shifting led to superior performance. For every gear shift, *Bicycling* accurately measured the beginning and end points generating a rating from 1 to 10, with 10 denoting the highest shifting speed. *Shifting Smoothness*$_{fts}$ measured the complete number of accurate gear changes for a gear-shifting set s produced by a firm f at time t across a range of 16 shifts. The measure from *Bicycling* used a variable scale of 1 to 10, with 10 being the best smoothness rating.

Independent Variables

Design Internalization$_{fst}$ is an independent variable for testing Hypotheses 1a and 2a. It refers to whether a firm f designed the outsourced components for a certain gear-shifting set s at time t in-house. We focus on the non-derailleur gear-shifting component outsourcing as noted in the *Research Context* section. *Bicycling*'s Super Spec database provided information as to which firm designed a particular gear-shifting set *s*.[11] If a firm *f* was found to have designed the components for gear-shifting set *s*, then the suppliers for firm *f* needed to follow the prescriptions regarding component specifications (i.e., design rules) imposed by firm *f* in an outsourcing situation. Thus, *Design Internalization*$_{fst}$ was equated to 1 if a gear-shifting set *s* was marked as being designed by firm *f* in the database. Otherwise, it was equated to 0 (i.e., *Design Externalization*$_{fst}$).

Technologically Upscale Market Choice (Up-Market Choice: MTB vs. RDB)$_{st}$ is an independent variable for Hypothesis 1b indicating whether a gear-shifting set *s* at time *t* was included in the MTB or RDB market. *Up-Market Choice (MTB vs. RDB)*$_{st}$ was set to 1 if the gear-shifting set was included in the MTB market. Otherwise, it was 0. Similarly, *Technologically Downscale Market Choice (Down-Market Choice: CTB vs. RDB)*$_{st}$ is an independent variable for Hypothesis 2b indicating whether a gear-shifting set *s* at time *t* was included in the CTB or RDB market. *Down-Market Choice (CTB vs. RDB)*$_{st}$ was set to 1 if the gear-shifting set was included in the CTB market. Otherwise, it was 0.

Control Variables

We also considered several control variables that may be related to our independent and dependent variables. Previous research has established that the adoption of a *Dominant Design*$_{fst}$ (in our case, whether a gear-shifting set *s* produced by a firm *f* was adopted as a dominant design at time *t*) is critical for survival (Suarez & Utterback, 1995). As such, we anticipated this variable to influence shifting performance, and thus we controlled for it. Derailleur firms eventually came to understand that for a gear-shifting set to provide premium shifting performance, eight key features (none of which existed in the pre-index shifting era) had to be integrated into the gear-shifting set. Four features involved the derailleur, two features involved the freewheel, one feature involved the

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[11] The database specifies each firm's design rule by name – Shimano (*S.I.S*), SunTour (*AccuShift*), Campagnolo (*Syncro*), Huret/Sachs (*ARIS*)), etc. For example, *AccuShift* indicates SunTour's distinctive design rule regarding its gear-shifting components – both derailleur and non-derailleur components. In an outsourcing situation, suppliers of components with the *AccuShift* designation had to follow SunTour's designated design rule.

chain, and one feature involved the shifter (*Bicycling,* Dec./1986, p.30-31; Feb./1987, p.92-96; Mar./1987, p.38-41; Dec./1989, p.96-100).[12] We used *Bicycling*'s Super Spec database and *Sutherland's Handbook for Bicycle Mechanics* together to track these dominant design features in each gear-shifting set. If these eight features were incorporated into a gear-shifting set, *Dominant Design*$_{fst}$ was coded as 1; otherwise 0.

We controlled for *Patents*$_{ft}$ in this study given that patents can indicate a firm's absorptive capacity for a given innovation (Cohen & Levinthal, 1990). We used the total number of patents (based exclusively on the U.S. market) that a firm *f* acquired over a three-year period by year *t*. Among many subclasses related to the whole bicycle, we found patent subclasses 474/78-297 and 475/269-330 (i.e., Bicycle Gear Shifting, Index Shifting Components) were most related to gear-shifting sets. We also consulted with three industry specialists (i.e., two *Bicycling/Bike-tech* trade magazine technical editors and one editor at *Bicycle Manufacturers' Association of America*), and they agreed with our judgment on the patent subclasses. We then counted the number of patent applications in these subclasses filed by a firm within the three years previous to the firm's commercialization of a new gear-shifting set.

We controlled for product differentiation by price using two dummy variables. *Bicycling* provided product price segments within the bicycle market: high-, middle-, and low-price segments. *ProductDifferentiation_H/L*$_{st}$ and *ProductDifferentiation_M/L*$_{st}$ were coded to 1 if a gear-shifting set *s* at time *t* was incorporated into the high-level and middle-level price segments; otherwise 0 (i.e., the low-level price segment was a reference point and was coded as 0 in both variables).

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[12] These eight new critical features (which were not incorporated into non-index gear-shifting sets) include the following:
- 4 features in the derailleur: a spring number and tension design, a new pivot angle design, a new pulley spacing design, and a new cage geometry design
- 2 features in the freewheel: a new narrow cog gap design and grinded cog teeth design
- 1 feature in the chain: a different chain width design
- 1 feature in the shifter: an indexed shifter lever and cable tension design

We also included *Manufacturing (Make Firm)*$_{fst}$ in our analyses indicating that a firm *f* manufactured a gear-shifting set *s* in-house at time *t*. Much existing research has argued for internalized component sourcing over externalized component sourcing for performance benefits (Wolter & Veloso, 2008). We thus controlled for *Manufacturing (Make Firm)*$_{fst}$.

Sourcing Duration$_{st}$ can potentially affect performance (Gulati, 1995; Hoetker, 2005). *Sourcing Duration*$_{st}$ measured the duration (the number of years) that a firm *f* and its existing supplier partnered together for a gear-shifting system *s* at time *t*. More than 90% of bicycle firms worked with a single supplier while others worked with a couple of suppliers (the maximum number of suppliers sourced by a firm in the market was two). In such cases, we calculated the duration (un-weighted average) of recurring transactions with these suppliers.

We also controlled for firm size and age. *Firm Size*$_{ft}$ was represented by the production capacity of a firm indicating the total number of gear-shifting models that a firm *f* produced for the entire bicycle market in year *t*, which includes all bicycle types. A few scholars have suggested that larger firms are slow to adopt new innovations because of organizational inertia (Blau & Schoenherr, 1971) while others assert that larger firms possess a greater amount of resources that can serve as a buffer when managing innovations (Galbraith, 1968). Our prospect regarding this variable is neutral due to these contrasting assertions. *Firm Age*$_{ft}$ captured the length of time (in years) that a firm *f* produced derailleur components by year *t*. Some scholars contend that architectural innovations are often mismanaged by incumbents (Christensen, 1997) while some contend the reverse (Chandy & Tellis, 2000). Our prospect regarding this variable is neutral as well due to these contrasting assertions.

Experience with Index Shifting Innovation$_{ft}$ was another control variable and was assessed by the length of time elapsed from when a firm *f* first adopted the innovation of index-shifting technology in year *t*. Due to the high degree of interdependence among components that inherently exist with architectural innovations, it may take time for firms to acquire new architectural knowledge (Henderson & Clark, 1990). Thus, firms characterized by a longer history of managing architectural innovations should display superior performance. In addition, the *Number of Suppliers*$_t$ may affect shifting performance. When only a limited population of suppliers for a specific resource exists in the market, such suppliers also recognize that limited alternatives are available. Therefore, they may find it easier to exploit the buyer's dependence and engage in opportunistic behaviors. We call such a situation the "small number bargaining" issue (Williamson, 1985). We controlled for *Number of Suppliers*$_t$ and measured it by the number of supplier firms in the market at year *t* in our study.

Finally, *Distance*$_{ft}$*,* the geographical distance between the head office of the originating firm (i.e., Shimano) and rival firm *f*, served as an instrumental variable for obtaining the predicted values of *Design Internalization*$_{fst}$. Since Shimano practiced design internalization, the closer a firm was to Shimano geographically, the more likely it would be to imitate Shimano's design sourcing approach.[13] The *Bicycle Manufacturers' Association of America* provided information about each firm's headquarters. Reasons for inclusion of this variable as an instrument are provided in the *Analysis* sub-section.

Analysis

As previously noted, the data sample garnered for our study contains information regarding bicycle gear-shifting sets sold between 1985 and 1995. The data are in unbalanced panel form. Even though the single gear-shifting set comprises our study's unit of analysis, our independent and control variables are a mixture of product- and firm-level variables. Multiple gear-shifting sets are also presented in the same firm. As a result, OLS regression is not suitable for our analysis. Thus,

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[13] For example, Japanese firms tended to exhibit the same sourcing choices as each other, and Italian firms also tended to exhibit the same sourcing choices as each other.

when considering a random vs. fixed effects model, we selected the random effects model because any time invariant variables (e.g., $ProductDifferentiation\_H/L_{st}$, $ProductDifferentiation\_M/L_{st}$) cannot be separated from the fixed effects. We also ran Hausman's (1978) specification test, which indicated that the random effects model was appropriate.

Statistical analysis showed that another important issue in this study is endogeneity arising from the design internalization vs. externalization decision (Greene, 2003; Hamilton & Nickerson, 2003). This sourcing decision could bend in one direction due to a firm's tendency to select one design approach over another given its specific capabilities or constraints. Over time, firms may switch from design internalization to design externalization or vice versa due to their initial undesirable outcomes. We thus employed 2SLS (two-stage least squares approach) to mitigate the endogeneity issue. Two stages are jointly estimated: the first of the two stages in the 2SLS approach deals with firms' design sourcing decisions when addressing an architectural innovation. The objective of this initial stage is to generate predicted values for the firm design sourcing choice (*Predicted_Design Internalization*). This is then utilized in the second stage (i.e., *Eq. (2)* performance model below).

$$Design\ Internalization_{fs(t+1)} = \beta_0 + \beta_1 {*} Control\ Variables_{fst} + \beta_2 {*} Distance_{ft} + \varepsilon_{fst} \qquad Eq.\ (1)$$

where s is the gear-shifting system for firm f, and t is time.

$Distance_{ft}$ serves as an instrumental variable in the design sourcing decision model. To be an appropriate instrument, it should satisfy (at least) three key requirements – exclusion restriction, endogeneity, and relevance. Regarding exclusion restriction, the impact of our instrument $Distance_{ft}$ on our dependent variables (*Shifting Speed* and *Shifting Smoothness*) is arguably mediated fully by our independent variable, $Design\ Internalization_{fst}$. If the geographical distance is short between the originating firm (Shimano) and rival firms, then the likelihood of imitating each other's sourcing choices could be higher (exhibiting a negative relationship between geographic distance and the design internalization likelihood), which could in turn affect the performance measures. However, the distance between Shimano and its rivals is unlikely to directly affect our performance measures. Without considering the impact of our independent variable (i.e., $Design\ Internalization_{fst}$) on the dependent variables, the impact of the instrument $Distance_{ft}$ on the dependent variables cannot be logically explained. Thus, our instrument has reasonably satisfied the exclusion restriction from the conceptual standpoint.

Regarding both endogeneity and relevance (Lu, Ding, Peng, & Chuang, 2018), we first determined whether endogeneity was a legitimate concern. The Durbin-Wu-Hausman test indicated the presence of strong endogeneity in our model in the MTB market ($p = 0.0056$). Similar results were also obtained with the CTB market ($p = 0.016$) causing us to reject the null hypothesis of exogeneity. Next, we turned our attention to the relevance test to determine how likely the instrumental variables predicted our study's explanatory variables (Murray, 2006). The smallest F (eigenvalue) statistic (Kleibergen & Paap, 2006) exceeded 16.00 (significant at the 10% level) in both the MTB and CTB markets. Conventionally, the F statistic should exceed 10.0 to denote reliable two-stage regression estimators (Stock, Wright, & Yogo, 2002). In short, our tests suggest that our study's instrument is statistically valid.

Finally, we estimated the following performance equation:

$$Performance_{fs(t+1)} = \alpha_0 + \alpha_1 * Up\text{-}Market\ Choice\ (MTB\ vs.\ RDB) + \alpha_2 * Down\text{-}Market\ Choice\ (CTB\ vs.\ RBD) + \alpha_3 * Predicted\_Design\ Internalization_{fst} + \alpha_4 * Control\ Variables_{fst} + \varepsilon_{fst} \quad Eq.\ (2)$$

where s is the gear-shifting system for firm f, and t is time.

RESULTS

The means, standard deviations, and correlations for our study's variables are displayed in Tables 1 and 2. On the whole, the correlations among our study's independent variables are relatively low.

----- Insert Tables 1, 2, 3 and 4 around here ----

----- Insert Figures 4(a), 4(b), 5(a), and 5(b) around here -----

In testing our hypotheses, we first used the analyses of the RDB market subsample – the originating market of index shifting innovation – as the baseline. The results of Model 1 in Tables 3 and 4 suggest that the coefficients for *Predicted _Design Internalization* in Model 1 of Tables 3 and 4 are both positive and significant in the RDB market (+2.451, $p < 0.01$, in Model 1 of Table 3; +2.183, $p < 0.01$, in Model 1 of Table 4). These results are largely consistent with those of previous studies (Park & Ro, 2011).

We then used Model 2 with the MTB subsample to test Hypothesis 1a in Tables 3 and 4. The coefficients for *Predicted_Design Internalization* in Model 2 from Tables 3 and 4 are both positive and significant in the MTB market (+4.056, $p < 0.01$, in Model 2 of Table 3; +3.227, $p < 0.01$, in Model 2 of Table 4) indicating that the products from firms pursuing design internalization tended to outperform those from firms pursuing design externalization in the MTB market. In addition, the grouped *t*-test results in Figures 4(a) and 4(b) indicate a positive and significant performance difference between design internalization and design externalization in the MTB market (t *(DI-DE)* = 13.19, $p < 0.01$ for *Shifting Speed;* t *(DI-DE)* = 6.93, $p < 0.01$ for *Shifting Smoothness*). These results support Hypothesis 1a.

Model 3 with combined subsamples from the MTB and RDB markets tests Hypothesis 1b in Tables 3 and 4. The coefficients for *Up-Market Choice (MTB(1) vs. RDB(0))* in Model 3 are both positive and significant (+2.151, $p < 0.01$, in Model 3 of Table 3; +1.687, $p < 0.01$, in Model 3 of Table 4). These results indicate that the performance impact of design internalization became stronger in the subsequent technologically upscale MTB market than in the originating RDB market. A grouped *t*-test was also performed: the results are depicted in Figures 4(a) and 4(b) and indicate the significant differences in technological performance of design internalization in the MTB and

RDB markets $t\ (DI_{MTB}\text{-}DI_{RDB}) = 8.59$, $p < 0.01$ for *Shifting Speed*; $t\ (DI_{MTB}\text{-}DI_{RDB}) = 14.46$, $p < 0.01$ for *Shifting Smoothness*). These results overall support Hypothesis 1b.

Model 5 with the CTB subsample in Tables 3 and 4 was used to test Hypothesis 2a. The coefficients for *Predicted_Design Internalization* in Model 5 of Tables 3 and 4 are both negative and significant in the CTB market (-2.188, $p < 0.01$ in Model 5 of Table 3; -2.572, $p < 0.01$ in Model 5 of Table 4) indicating that the products from firms pursuing design internalization tended to underperform those from firms pursuing design externalization in the CTB market. In addition, the grouped *t*-test results in Figures 5(a) and 5(b) indicate a significant performance difference between design internalization and design externalization in the CTB market only in terms of *Shifting Speed* ($t\ (DI\text{-}DE) = 1.78$, $p < 0.1$) but not *Shifting Smoothness*. Overall, these results partially support Hypothesis 2a.

Finally, Model 6 with combined subsamples from the CTB and RDB markets tests Hypothesis 2b in Tables 3 and 4. The coefficients for *Down-Market Choice (CTB(1) vs. RDB (0))* are both negative and significant (-1.771, $p < 0.01$, in Model 6 of Table 3; -1.132, $p < 0.01$, in Model 6 of Table 4) indicating that the performance impact of design internalization became weaker in the subsequent technologically downscale CTB market than in the originating RDB market. In addition, the results of a grouped *t*-test in Figures 5(a) and 5(b) indicate significant differences in the technological performance of design internalization in the CTB and RDB markets ($t\ (DI_{CTB} – DI_{RDB}) = -4.36$, $p < 0.01$ for *Shifting Speed*; $t\ (DI_{CTB} – DI_{RDB}) = -8.60$, $p < 0.01$ for *Shifting Smoothness*). These results overall yield support for Hypothesis 2b.

ROBUSTNESS CHECKS

----- Insert Table 5 around here ----

We are also aware that the MTB market adopted index shifting technology in 1987 while the CTB market adopted it in 1988. As a robustness check, we tested Hypotheses 1a and 1b with the

MTB data excluding MTBs appearing in 1987; thus, the MTB subsample would be on a comparable basis as the CTB subsample in terms of innovation adoption timing. The results are similar with those based on the original data. The coefficients for *Predicted_Design Internalization* in Models 1 and 2 of Table 5 are both positive and significant in the MTB market (+3.937, $p < 0.01$, for *Shifting Speed* in Model 1 of Table 5; +2.987, $p < 0.01$, for *Shifting Smoothness* in Model 2 of Table 5). These data indicate that the products from firms pursuing design internalization also tended to outperform those from firms pursuing design externalization in the MTB market. These results support Hypothesis 1a. In addition, the coefficients for *Up-Market Choice (MTB(1) vs. RDB(0))* in Models 3 and 4 of Table 5 are both positive and significant (+1.907, $p < 0.01$, for *Shifting Speed* in Model 3 of Table 5; +1.604, $p < 0.01$, for *Shifting Smoothness* in Model 4 of Table 5) indicating that the performance impact of design internalization also became stronger in the subsequent technologically upscale MTB market than in the originating RDB market. These results support Hypothesis 1b overall.

DISCUSSION

Key Findings

Our key findings are first, when an architectural innovation has traversed to a technologically upscale market (i.e., the MTB market) from its originating market (i.e., the RDB market), design internalization is a superior sourcing choice to design externalization in the subsequent upscale market. Our findings also suggest that the performance impact of design internalization is stronger in the subsequent upscale market than in the originating market. Conversely, when the innovation has entered a technologically downscale market (i.e., the CTB market), design externalization becomes a superior sourcing choice to design internalization in the subsequent downscale market, and the performance impact of design internalization is weaker in such a market than in the originating market. These findings collectively suggest the important roles of knowledge spillover, exchange hazards, and technological market requirements that can potentially alter the performance impact of the make vs. buy design sourcing choice when facing a high-stakes innovation.

Theoretical Implications

These findings offer important theoretical contributions to the current technology and operations management literature as follows. First, this study contributes to the ongoing discourse concerning the make vs. buy sourcing choice regarding innovations. While some studies argue for an internalized (make) over externalized (buy) sourcing choice along the technological evolution of an innovation (Afuah, 2001; Monteverde, 1995; Williamson, 1985), others argue for the opposite (Balakrishnan & Wernerfelt, 1986; Powell et al., 1996). Our findings have furthered this conversation by focusing on the case of an architectural innovation and by suggesting that the technological performance of products can be best achieved via any of the two sourcing choices contingent on the technological requirements of the originating and subsequent markets.

Second, this study contributes to the strategic sourcing literature related to architectural innovations (Kapoor & Adner, 2012; Park et al., 2018; Park & Ro, 2011). One of the established stances is that in dealing with architectural innovations, internalizing design (and manufacturing) will likely lead to better performance than externalizing design (and manufacturing) (Kapoor & Adner, 2012; Park & Ro, 2011). Another stance is that design internalization can negatively affect performance across an innovation's life cycle (Park et al., 2018). Expanding beyond these issues, this study offers a more refined awareness of the design sourcing choice and its effectiveness in the contexts of architectural innovation and market-dependent technological requirements. This study uses an empirical setting where the knowledge spilled over from the originating market of the innovation to two subsequent markets with different levels of requisite technological performance. Thus, the occurrence of such innovations in these different markets can be largely viewed as interrelated rather than discrete events. Within this view, the performance impact of design sourcing choices in subsequent markets can vary with their requisite technological demands. In short, our findings suggest a more dynamic view on the design sourcing choice, market technological requirements, and sequential occurrences of innovation in different markets. This dynamic view can enrich the strategic sourcing literature and is a worthwhile area for future research pursuits.

Third, our findings can potentially put the theoretical thrust of design lock-in into perspective (Cyert & March, 1963; Leonard-Barton, 1992; Nelson & Winter, 1982). The (design) lock-in argument seems to suggest that firms should seek external sources of innovation when operating in a market with high technological requirements (Balakrishnan & Wernerfelt, 1986; Powell et al., 1996). Such a strategy can overcome the rigidities accrued from their previous experience and routines built around their existing product architecture. Thus, externalized design activities would be desirable. However, our empirical results appear contrarian to the design lock-in implications for products targeting a market with high technological requirements. It is possible that the intricacies of the design sourcing choice, market technological requirements, and knowledge spillovers in the empirical setting of our study may go beyond the basic arguments of design lock-in. Our findings can motivate future research to revisit the boundary conditions of design lock-in.

Finally, our study uniquely examines the advent of an architectural innovation in its originating market and in its subsequent markets. We treat follow-up architectural innovations for subsequent markets as interrelated events arguably through knowledge spillovers between the markets. This study thus brings together the key arguments in the architectural innovation and knowledge spillover literatures (Jaffe, 1986; Mansfield, 1985; Yang et al., 2010) to explain the performance implications of design sourcing choices for different markets. Previous research on knowledge spillovers has focused largely on horizontal alliances and knowledge sharing/receiving among firms within their market or industry. Expanding from that direction, this study highlights the theoretical plausibility of knowledge spillovers across markets with distinct technological demands and hierarchical knowledge requirements (i.e., upscale vs. downscale). In this sense, our study highlights a vertical dimension of knowledge spillovers and exchanges, which could be a promising research area to further enrich the knowledge spillover literature.

Managerial Implications

Our study also provides important managerial insight for design sourcing in innovation management. When an architectural innovation occurs and succeeds in one market, many managers may want to strategically leverage such an innovation in another market. However, they need to be mindful of the requisite level of technological performance demanded in the new market vis-à-vis that in the originating market when deciding whether to internalize or externalize their firm's design activities. Our findings suggest that while design internalization is critical to success in the originating market, blindly replicating such practice in a technologically downscale market could prove counterproductive given the adequate knowledge from downward spillovers and the lower technological requirements in the downscale market. On the other hand, design internalization in tandem with additional investments in knowledge-based design activities are needed to successfully harness the architectural innovation in a technologically upscale market given the knowledge gap created by upward spillovers and the higher technological requirements in the upscale market.

Limitations and Future Research

This study has some limitations that can guide future research. First, technological performance is the focus of the performance measure for the impact of design sourcing choices in this study. Investigating the impact of the design sourcing choice on other performance measures such as market standing (e.g., sales, market share) and financial performance (e.g., margins, profitability) would be a logical extension from this study. Through design internalization, firms may be able to accomplish technological performance benefits, but such benefits may or may not come with tangible gains in market standing or financial performance measures, at least near term.

It is possible that firms could even opt out of the superior design sourcing choice in terms of technological performance if there is a substantive tradeoff in market standing or financial performance. Further research regarding the market and financial performance impacts of the design sourcing choice would thus provide a more complete view on the performance and design sourcing inquiry and would be a worthwhile pursuit in the future.

Second, we theoretically maintained that knowledge spillover is a key mechanism for knowledge acquisition/learning among industry players when an architectural innovation has moved from its originating market to subsequent technologically upscale and downscale markets. However, we did not systematically operationalize knowledge spillover beyond simply providing anecdotal evidence of the key design features similar or dissimilar across those markets in our study. Measuring knowledge spillover with a finer scale would enable future studies to assess the extent to which knowledge spillovers across different markets can alter the performance impact of design sourcing choices in those markets with greater nuances.

Finally, this study focuses on three bicycle markets within a single industry. Thus, the validity of our findings may be confined to industries where the products have similar architectures and comparable levels of complexity to those in our study. When the interfaces of components in the product architecture become more complex, such as those in smartphones, it is possible that knowledge spillover could become less effective in facilitating knowledge diffusion and acquisition among industry players. Future research can build on this study by examining the performance impact of design sourcing choices and knowledge spillover in the context of industries with complex product architectures. This line of research will reveal the boundary conditions within which the findings of this study remain valid, and will enrich the literature on the interplay of the design sourcing choice, architectural innovation, and knowledge spillover.

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Figure 1(a): Bicycle Markets with Varying Degrees of Performance – Shifting Speed (Average ± Standard Deviation).

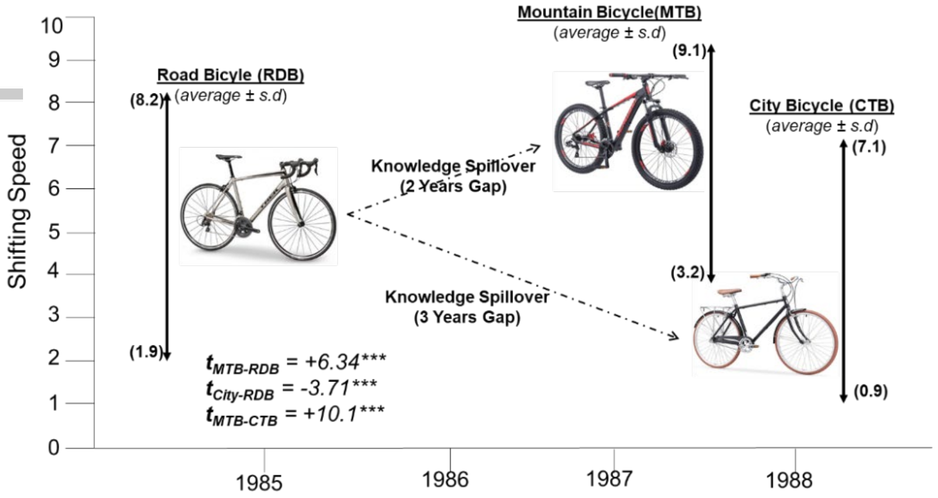


Figure 1(b): Bicycle Markets with Varying Degrees of Performance – Shifting Smoothness (Average ± Standard Deviation).

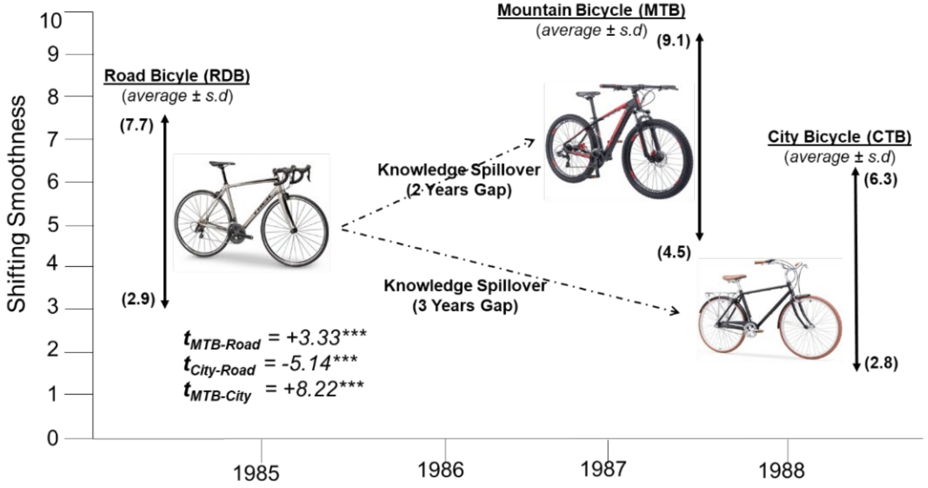


Figure 2: Bicycle Subsystems and Design Sourcing Choice.

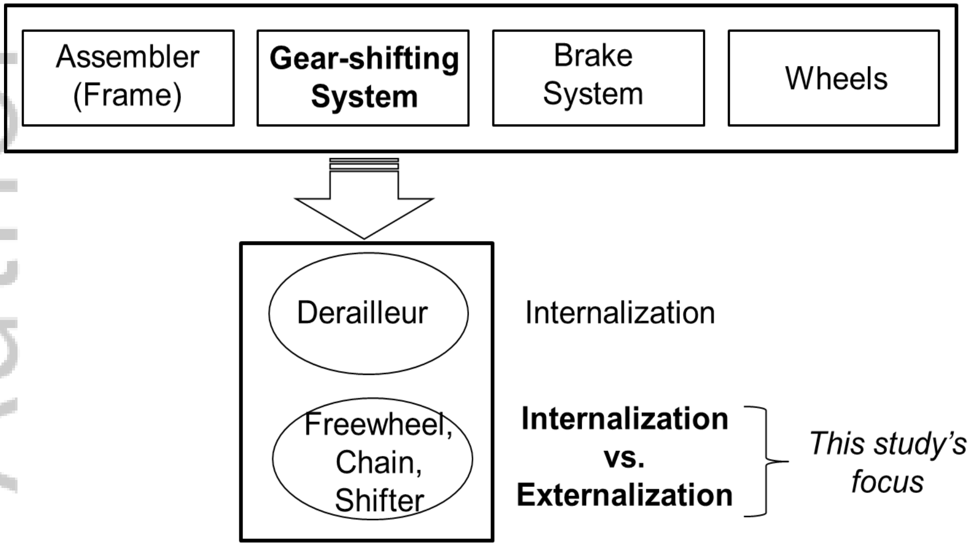
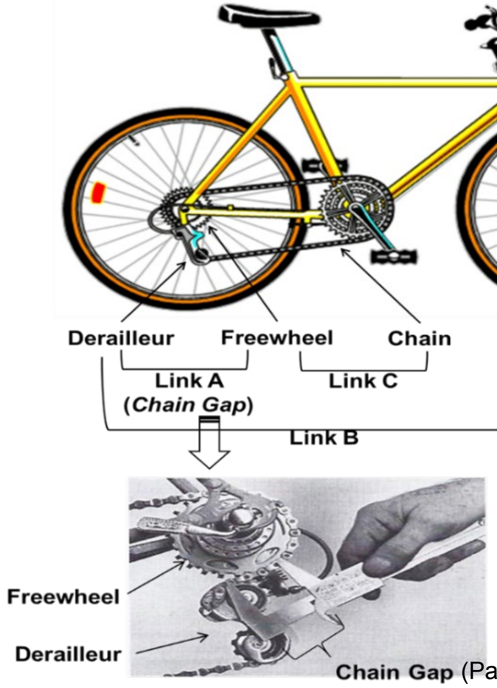


Figure 3: Bicycle Gear-shifting System, Key Linkages, and Chain Gap.



(Park et al. 2018, pp.330)

Figure 4(a): Shifting Speed and Design Sourcing - RDB vs. MTB.

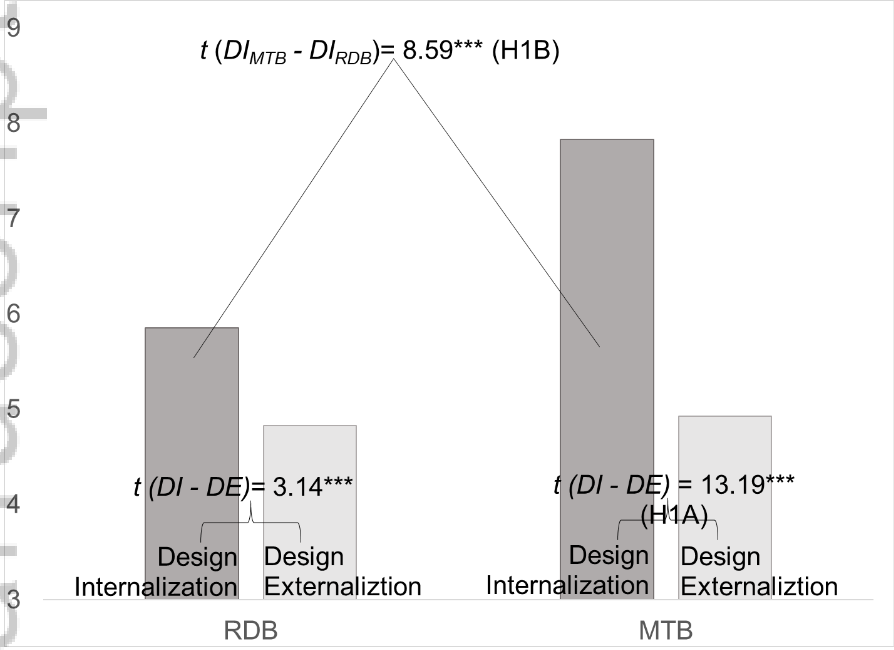


Figure 4(b): Shifting Smoothness and Design Sourcing - RDB vs. MTB.

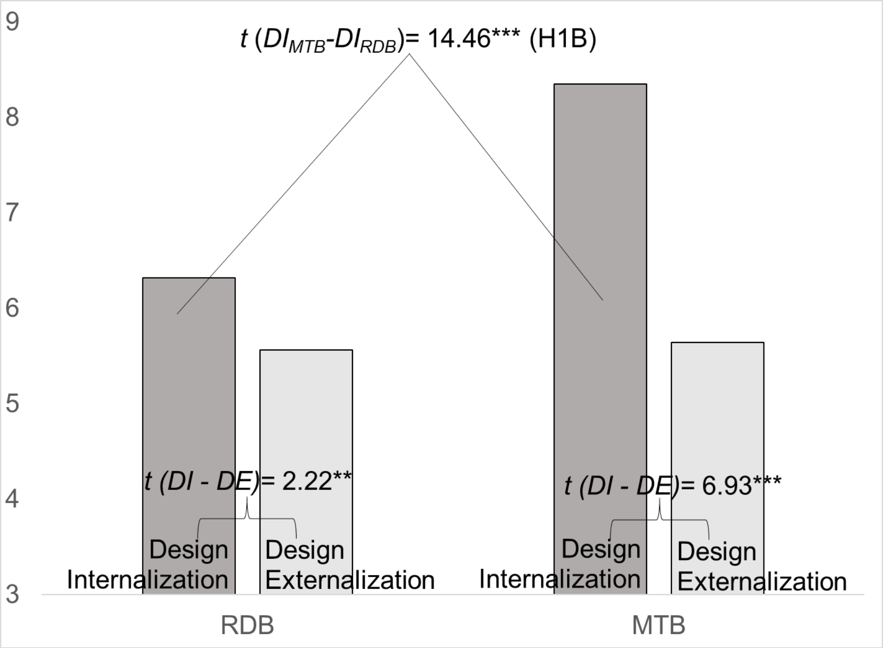


Figure 5(a): Shifting Speed and Design Sourcing - RDB vs. CTB.

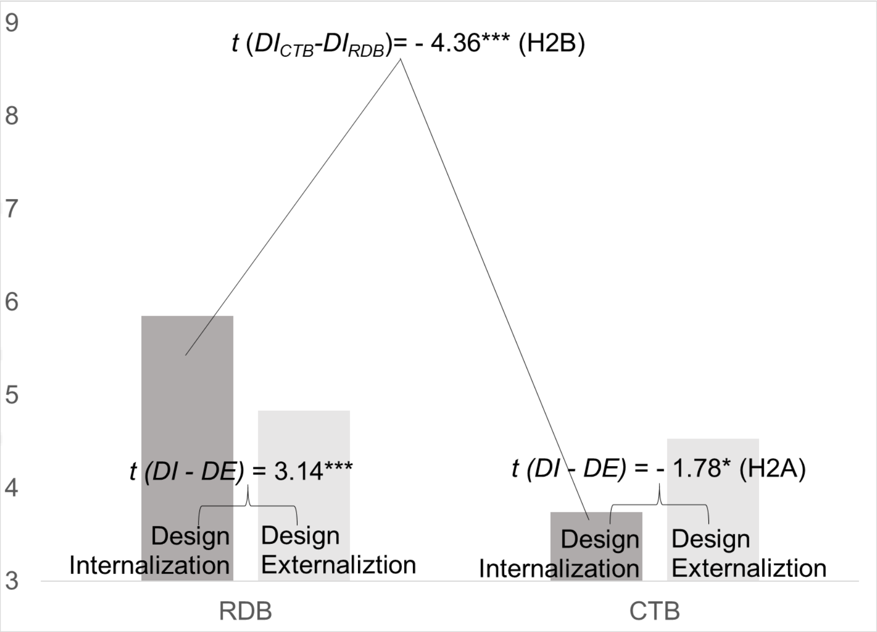


Figure 5(b): Shifting Smoothness and Design Sourcing - RDB vs. CTB.

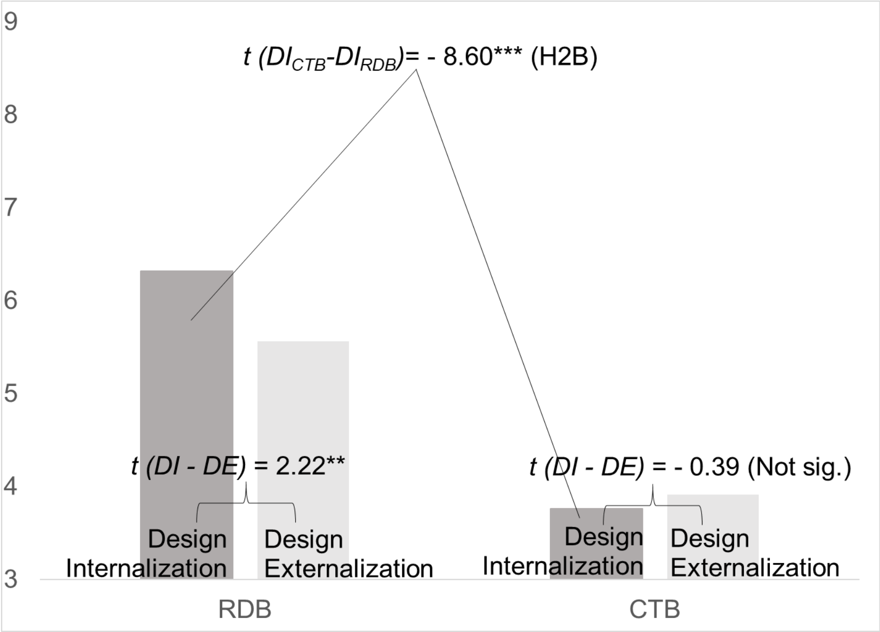


Table 1: Descriptive Statistics and Correlations for Mountain Bicycle Market

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Shifting Speed	1.000														
2	Shifting Smoothness	+0.523	1.000													
3	Index Shifting Innovation	+0.242	+0.294	1.000												
4	Design Internalization	+0.342	+0.476	- 0.128	1.000											
5	Dominant Design	+0.041	+0.123	+0.056	+0.051	1.000										
6	Patents	+0.043	+0.067	- 0.068	- 0.009	- 0.088	1.000									
7	Product Differentiation H/L	+0.069	- 0.024	+0.034	- 0.152	- 0.032	+0.009	1.000								
8	Product Differentiation M/L	- 0.008	+0.091	+0.093	+0.088	+0.144	+0.065	- 0.335	1.000							
9	Manufacturing (Make)	+0.224	+0.201	- 0.039	+0.009	+0.124	+0.058	+0.019	- 0.013	1.000						
10	Sourcing Duration	- 0.228	- 0.185	-0.162	- 0.266	- 0.090	- 0.037	+0.158	- 0.049	- 0.108	1.000					
11	Firm Size	+0.065	+0.004	+0.173	+0.044	- 0.056	+0.030	- 0.029	- 0.042	- 0.059	- 0.044	1.000				
12	Firm Age	+0.142	- 0.001	- 0.126	+0.063	- 0.049	- 0.099	+0.079	- 0.060	- 0.104	+0.167	+0.079	1.000			
13	Experience on Index	+0.207	+0.159	+0.170	+0.277	+0.007	+0.043	- 0.129	+0.381	+0.073	- 0.227	+0.151	-0.121	1.000		
14	No. of Suppliers	- 0.092	- 0.089	- 0.156	- 0.174	- 0.074	- 0.146	+0.173	- 0.234	- 0.004	+0.145	- 0.053	+0.124	- 0.357	1.000	
15	Distance	- 0.028	- 0.049	- 0.011	- 0.347	+0.059	+0.084	+0.013	+0.033	+0.039	- 0.051	- 0.036	- 0.021	+0.027	- 0.145	1.000
	Mean	6.105	6.660	0.718	0.538	2.138	2.707	0.299	0.204	0.159	6.292	0.058	24.52	3.164	34.37	3.321
	S.D.	2.967	2.454	0.451	0.451	1.101	2.673	0.459	0.403	0.367	2.743	0.141	16.05	2.487	8.321	2.450
	Max	10.00	10.00	1.000	1.000	3.000	8.000	1.000	1.000	1.000	12.00	0.700	51.00	9.000	42.00	9.457
	Min	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.001	2.000	0.000	16.00	0.000

Table 2: Descriptive Statistics and Correlations for City Bicycle Market

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Shifting Speed	1.000														
2	Shifting Smoothness	+0.746	1.000													
3	Index Shifting Innovation	+0.402	+0.364	1.000												
4	Design Internalization	+0.117	- 0.027	- 0.176	1.000											
5	Dominant Design	- 0.009	+0.027	-0.098	+0.030	1.000										
6	Patents	- 0.049	- 0.081	+0.089	- 0.067	- 0.089	1.000									
7	Product Differentiation H/L	- 0.049	+0.045	+0.016	- 0.078	- 0.033	- 0.004	1.000								
8	Product Differentiation M/L	- 0.092	- 0.112	+0.092	- 0.012	+0.019	+0.040	- 0.380	1.000							
9	Manufacturing (Make)	- 0.499	- 0.404	+0.143	- 0.287	- 0.024	+0.013	+0.038	+0.051	1.000						
10	Sourcing Duration	+0.154	+0.085	- 0.067	+0.026	- 0.089	- 0.156	+0.112	- 0.099	- 0.151	1.000					
11	Firm Size	- 0.083	- 0.020	+0.136	- 0.039	+0.016	+0.015	+0.085	- 0.050	+0.002	+0.209	1.000				
12	Firm Age	- 0.276	- 0.249	- 0.051	+0.022	+0.001	- 0.056	- 0.009	+0.071	+0.069	+0.026	+0.058	1.000			
13	Experience on Index	- 0.238	- 0.218	+0.120	- 0.026	+0.001	+0.056	- 0.005	+0.383	+0.221	- 0.059	+0.087	+0.030	1.000		
14	No. of Suppliers	+0.180	+0.142	- 0.155	+0.157	+0.018	- 0.044	+0.111	- 0.106	- 0.134	- 0.090	- 0.216	- 0.077	- 0.219	1.000	
15	Distance	- 0.014	+0.025	- 0.017	- 0.365	+0.064	+0.098	- 0.006	+0.009	+0.080	- 0.117	- 0.072	+0.073	+0.030	- 0.096	1.000
	Mean	3.591	3.849	0.723	0.290	2.102	2.696	0.333	0.222	0.335	6.688	0.060	27.92	3.246	34.08	3.246
	S.D.	3.110	2.465	0.448	0.456	1.081	2.708	0.472	0.417	0.473	2.735	0.149	16.19	2.600	8.592	2.374
	Max	10.00	10.00	1.000	1.000	3.000	8.000	1.000	1.000	1.000	12.00	0.700	51.00	9.000	42.00	9.457
	Min	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.001	2.00	0.000	16.00	0.000

Table 3: Estimation Results based on 2SLS Regression for Shifting Speed

Dependent Variable: Shifting Speed	RDB only	MTB Only	MTB + RDB	MTB + RDB	CTB Only	CTB + RDB	CTB + RDB
	All Sample	All Sample	Design Internal.	Design External.	All Sample	Design Internal.	Design External.
	Model 1	Model 2 (H1a)	Model 3 (H1b)	Model 4	Model 5 (H2a)	Model 6 (H2b)	Model 7
Predicted_Design Internalization	+2.451 (0.418)***	+4.056 (0.569)***	-------	-------	- 2.188 (0.516)***	-------	-------
Up-Market Choice (MTB(1) vs. RDB(0))	-------	-------	+2.151 (0.418)***	+0.396 (0.299)	-------	-------	-------
Down-Market Choice (CTB(1) vs. RDB(0))	-------	-------	-------	-------	-------	- 1.771 (0.558)***	+0.399 (0.304)
Dominant Design	- 0.098 (0.144)	+0.197 (0.184)	- 0.083 (0.181)	+0.133 (0.111)	- 0.143 (0.132)	+0.012 (0.231)	- 0.189 (0.114)*
Patents	+0.110 (0.061)*	+0.155 (0.083)*	- 0.065 (0.066)	- 0.017 (0.048)	- 0.135 (0.058)**	+0.007 (0.083)	- 0.001 (0.051)
Product Differentiation High(1)/Low(0)	+0.573 (0.374)	+0.243 (0.503)	+0.184 (0.443)	+0.445 (0.308)	- 0.484 (0.349)	- 0.346 (0.543)	- 0.061 (0.336)
Product Differentiation Middle(1)/Low(0)	- 0.363 (0.402)	+0.175 (0.636)	+0.141 (0.416)	- 0.315 (0.347)	+0.406 (0.392)	+0.379 (0.597)	+0.214 (0.346)
Manufacturing (Make Firm)	+0.527 (0.450)	+2.659 (0.950)***	+0.959 (0.450)**	+4.192 (0.370)***	- 2.492 (0.531)***	- 1.630 (0.637)**	- 1.505 (0.371)***
Sourcing Duration	- 0.032 (0.057)	- 0.054 (0.098)	+0.099 (0.061)	- 0.049 (0.045)	+0.055 (0.054)	- 0.061 (0.081)	- 0.232 (0.043)***
Firm Age	- 0.017 (1.023)	- 1.200 (1.561)	- 0.200 (1.152)	+0.066 (0.867)	- 0.494 (1.025)	- 0.769 (1.406)	- 1.792 (0.953)*
Firm Size	+0.071 (0.010)***	+0.043 (0.013)***	- 0.023 (0.009)**	+0.036 (0.008)***	- 0.058 (0.009)***	+0.205 (0.017)***	- 0.001 (0.008)
Experience on Index	+0.008 (0.068)	- 0.042 (0.102)	- 0.056 (0.079)	+0.144 (0.055)***	+0.011 (0.062)	+0.101 (0.109)	- 0.112 (0.057)*
No. of Suppliers	- 0.049 (0.019)**	+0.082 (0.031)***	- 0.016 (0.023)	- 0.020 (0.016)	+0.053 (0.020)***	+0.032 (0.029)	+0.035 (0.018)**
Constant	+1.926 (1.001)*	- 0.126 (1.426)	+4.063 (1.447)***	+3.661 (0.827)***	+7.175 (1.002)***	+3.783 (1.606)**	+4.602 (0.917)***
N	284	195	224	255	184	184	284
R^2	0.573	0.578	0.157	0.575	0.717	0.152	0.199
Wald Ch^2	251.81***	118.01***	45.38***	308.73***	357.51***	39.87***	64.64***

(1) ****p*<0.01, ***p*<0.05, **p*<0.1 (2) Robust (Cluster) standard error in parentheses

Table 4: Estimation Results based on 2SLS Regression for Shifting Smoothness

Dependent Variable: Shifting Smoothness	RDB only	MTB Only	MTB + RDB	MTB + RDB	CTB Only	CTB + RDB	CTB + RDB
	All Sample	All Sample.	Design Internal.	Design External.	All Sample	Design Internal.	Design External.
	Model 1	Model 2 (H1a)	Model 3 (H1b)	Model 4	Model 5 (H2a)	Model 6 (H2b)	Model 7
Predicted _Design Internalization	+2.183 (0.289)***	+3.227 (0.568)***	-------	-------	- 2.572 (0.559)***	-------	-------
Up-Market Choice (MTB(1) vs. RDB(0))	-------	-------	+1.687 (0.268)***	- 0.174 (0.212)	-------	-------	-------
Down-Market Choice (CTB(1) vs. RDB(0))	-------	-------	-------	-------	-------	- 1.132 (0.369)***	- 0.258 (0.205)
Dominant Design	+0.211 (0.124)	+0.067 (0.192)	+0.292 (0.111)***	- 0.056 (0.079)	- 0.052 (0.135)	+0.276 (0.151)*	- 0.067 (0.078)
Patents	+0.065 (0.050)	+0.205 (0.089)**	- 0.073 (0.042)*	+0.062 (0.034)*	- 0.140 (0.056)**	- 0.052 (0.055)	+0.034 (0.034)
Product Differentiation High(1)/Low(0)	- 0.102 (0.318)	- 0.394 (0.518)	+0.436 (0.280)	+0.581 (0.217)***	- 0.308 (0.353)	- 0.291 (0.359)	+0.131 (0.234)
Product Differentiation Middle(1)/Low(0)	+0.150 (0.342)	- 0.384 (0.662)	+0.532 (0.266)**	- 0.284 (0.245)	+0.420 (0.396)	- 0.284 (0.394)	- 0.129 (0.239)
Manufacturing (Make Firm)	+0.717 (0.391)*	+0.597 (0.984)	+0.595 (0.297)**	+3.494 (0.260)***	- 1.479 (0.564)***	- 1.223 (0.429)***	+0.078 (0.249)
Sourcing Duration	+0.090 (0.048)*	+0.155 (0.101)	- 0.069 (0.038)*	+0.041 (0.032)	- 0.077 (0.055)	- 0.072 (0.054)	- 0.194 (0.029)***
Firm Age	- 0.181 (0.823)	- 1.973 (1.710)	+0.838 (0.796)	+0.152 (0.607)	+0.530 (0.962)	- 0.305 (0.941)	- 0.251 (0.640)
Firm Size	+0.027 (0.009)***	+0.012 (0.014)	+0.007 (0.006)	+0.014 (0.006)**	+0.036 (0.009)***	- 0.017 (0.010)*	+0.009 (0.006)
Experience on Index	- 0.090 (0.060)	- 0.115 (0.107)	- 0.126 (0.048)***	- 0.080 (0.039)**	+0.017 (0.065)	+0.110 (0.072)	- 0.080 (0.041)**
No. of Suppliers	- 0.039 (0.016)**	+0.052 (0.032)	- 0.002 (0.017)	- 0.004 (0.011)	+0.043 (0.020)**	- 0.039 (0.019)**	+0.014 (0.012)
Constant	+2.895 (0.843)***	+1.654 (1.495)	+4.137 (0.958)***	+4.134 (0.582)***	+6.017 (0.997)***	+6.267 (1.063)***	+4.093 (0.623)***
N	284	195	224	255	184	184	284
R^2	0.453	0.434	0.191	0.539	0.529	0.362	0.183
Wald Ch^2	160.4***	78.51***	59.61***	273.31****	166.99***	91.40***	74.20***

(1) ****p*<0.01, ***p*<0.05, **p*<0.1 (2) Robust (Cluster) standard error in parentheses

Table 5: Robustness Check for H1a and H1b (MTB Data Excluding Bicycles in 1987) based on 2SLS Regression

	MTB Only (1987 Excluded)	MTB Only (1987 Excluded)	MTB (1987 Excluded) + RDB	MTB (1987 Excluded) + RDB
	(Shifting Speed)	(Shifting Smoothness)	Design Internal. (Shifting Speed)	Design Internal. (Shifting Smoothness)
	Model 1 (Robustness for H1a)	Model 2 (Robustness for H1a)	Model 3 (Robustness for H1b)	Model 4 (Robustness for H1b)
Predicted_Design Internalization	+3.937 (0.642)***	+2.987 (0.644)***	-------	-------
Up-Market Choice (MTB(1) vs. RDB(0))	-------	-------	+1.907 (0.421)***	+1.604 (0.276)***
Down-Market Choice (CTB(1) vs. RDB(0))	-------	-------	-------	-------
Dominant Design	+0.253 (0.214)	+0.100 (0.215)	- 0.097 (0.182)	+0.267 (0.113)**
Patents	+0.145 (0.092)	+0.199 (0.093)**	- 0.056 (0.065)	- 0.067 (0.044)
Product Differentiation High(1)/Low(0)	+0.009 (0.548)	- 0.506 (0.555)	+0.223 (0.450)	+0.426 (0.287)
Product Differentiation Middle(1)/Low(0)	+0.059 (0.727)	- 0.613 (0.733)	+0.100 (0.420)	+0.480 (0.271)*
Manufacturing (Make Firm)	+2.684 (1.012)***	+0.766 (1.012)	+1.163 (0.451)***	+0.664 (0.302)**
Sourcing Duration	- 0.037 (0.111)	+0.135 (0.113)	+0.085 (0.062)	- 0.078 (0.039)**
Firm Age	- 0.387 (1.777)	- 2.395 (1.797)	- 0.527 (1.169)	+0.782 (0.818)
Firm Size	+0.034 (0.015)**	+0.012 (0.015)	+0.027 (0.009)***	+0.005 (0.006)
Experience on Index	- 0.042 (0.117)	- 0.083 (0.117)	- 0.048 (0.082)	- 0.140 (0.050)***
No. of Suppliers	+0.087 (0.035)**	+0.064 (0.035)*	- 0.011 (0.026)	- 0.002 (0.018)
Constant	- 0.066 (1.603)	+1.654 (1.612)	+4.301 (1.453)***	+4.303 (0.978)***
N	184	184	233	233
R^2	0.557	0.428	0.149	0.191
Wald Ch^2	94.36***	58.79***	40.62***	59.61***

(1) ****p*<0.01, ***p*<0.05, **p*<0.1 (2) Robust (Cluster) standard error in parentheses

The Design Sourcing Choice and Technological Performance in the Upscale and Downscale Markets of an Architectural Innovation

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ABSTRACT

In this study, we study investigates the performance impacts of design sourcing choices in addressing an architectural innovation from its originating market to subsequent markets. We maintain that the effects of design internalization and externalization on the technological performance of firms' products may vary across the originating and subsequent markets with different requisite technological demands due to the dynamics of knowledge spillovers and knowledge exchange hazards in those markets. We hypothesize that design internalization is likely to outperform design externalization when facing an architectural innovation in a subsequent upscale market with a higher technological performance requisite than in the originating market. The case is then reverse in a subsequent downscale market with a lower technological performance requisite. We test our hypotheses in the empirical contexts of the U.S. bicycle markets in which the index gear-shifting technology (i.e., an architectural innovation) originated in the road bicycle market in 1985 and subsequently traversed to the mountain bicycle market (i.e., an upscale market) in 1987 and the city bicycle market (i.e., a downscale market) in 1988. The results are largely in line with our hypotheses. The contributions to the current literature of our study as well as its managerial implications are also discussed.

- Managers can strategically leverage an architectural innovation that occurs in one market to improve a product in another market.
- When a subsequent market of the architectural innovation is technologically upscale, managers should keep design activities of the product in-house to better manage the knowledge gap between the markets and the needed additional technological investments.
- Conversely, in a subsequent technologically downscale market, the knowledge spillovers between the markets facilitate the technological saturation and the proliferation of capable suppliers, making outsourcing the design activities more attractive to managers.

Key Words: Architectural Innovation, Design Sourcing Choice, Knowledge Spillover Effects, Knowledge Exchange Hazards, Technologically Upscale and Downscale Markets