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The Performance Benefits of Design Internalization across an Innovation's Life Cycle

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ABSTRACT

This study investigates the performance benefits of design internalization in outsourcing strategy. By incorporating the concept of an architectural innovation's life cycle, this study contributes to advancing the relevant literature regarding the impact of designing outsourced components in-house on technological performance in the face of architectural innovations.

KEYWORDS: Architectural Innovation, In-house External Component Design, Innovation Life Cycle

INTRODUCTION

When considering architectural innovations, the technological concepts underlying the components of a product are essentially unaltered, whereas the linkages between such components are significantly changed. Since the primary technological concept of each component basically remains unchanged, firms often mistakenly presume that they understand the underlying mechanisms of new architectural innovations. However, when confronting such innovations, firms frequently must switch to new modes of learning and create new information-processing routines to acquire new architectural knowledge (Henderson & Clark, 1990) because architectural knowledge tends to be embedded in organizational structures and routines. As a result, the theoretical and empirical examination of organizational alignments that considers the (dis)advantages of the make-buy decision in efficiently addressing new architectural innovations becomes important.

On the one hand, most modularity and technology management (M&TM) scholars (Baldwin & Clark, 2000; Fine, 1998; Sanchez & Mahoney, 1996; Afuah, 2001) tend to strongly presume that firms pursuing a make strategy will experience greater performance advantages than firms pursuing a buy strategy in the face of architectural innovations. On the other hand, recent M&TM studies emphasize the in-house retention of knowledge related to outsourced components as a factor enabling firms pursuing a buy strategy to improve performance in the face of architectural innovations (Brusoni, Prencipe, & Pavitt, 2001; Kapoor & Adner, 2012). In particular, Ulrich and Ellison (2005) investigate the function of internalizing the design activity of outsourced components and argue that readily designing outsourced components in-house (*In-house External Component Design*) is a critical and strategic matter when pursuing a buy strategy. Similarly, Park and Ro (2011) empirically demonstrated that firms retaining design capabilities in-house while pursuing an outsourcing strategy displayed significant improvement in technological performance. Even Apple, with their iPhone line, maintains control of the design aspects of key components including the internal antenna, retina display, and microprocessor chips while outsourcing their production, emphasizing their 'designed in California, made in China' approach. This case demonstrates the merits of maintaining design capability, and even performing the design function, of outsourced components within the firm.

However, recent studies have raised the possibility that the relative advantages of the make-buy sourcing decision can fluctuate across the innovation life cycle (Argyres & Bigelow, 2007; Lambe & Spekman, 1997; Novak & Stern, 2008). In the same vein, this study's overarching argument is that the role of *In-house External Component Design* may vary across the architectural innovation life cycle. Drawing on transaction cost economics (Williamson, 1991), the knowledge-based view (Nickerson & Zenger, 2004) and technology evolution theory (Abernathy & Utterback, 1978), we delve into the generally held belief among M&TM scholars that *In-house External Component Design* will positively affect performance. Specifically, we hypothesize that while *In-house External Component Design* can hinder firms that are pursuing a buy strategy from creating new architectural knowledge during the early period of an architectural innovation's life cycle (i.e., before the emergence of a dominant design), the performance benefits of *In-house External Component Design* can be realized in the later period (i.e., after the emergence of a dominant design).

To test our hypotheses, we examine the U.S. road bicycle drive train market from 1985 to 1995. More precisely, this study examines the performance implications of a derailleur firm's decision whether to readily design outsourced freewheel components in-house. Architecturally, the bicycle has evolved very little over the past century and most firms focused primarily on their own segment of the market (Galvin & Morkel, 2001). However, the drive train market underwent a significant architectural change in gear shifting technology in the mid-1980s by means of a new architectural innovation called index shifting (Fine, 1998; Fixson & Park, 2008). In particular, the linkages between the derailleur and freewheel significantly changed, directly affecting shifting performance. Since the vast majority of firms selling bicycle drive train sets produced the derailleur component in-house, investigating a derailleur firm's decision regarding whether to design outsourced freewheels in-house, and the impact of this decision on shifting performance, would provide a conducive research setting to test our hypotheses.

Our investigation of the bicycle drivetrain market supports our study's hypotheses. By incorporating the aspect of temporality (the innovation life cycle), our study is positioned as the first of many inquiries regarding the coevolving impact of *In-house External Component Design* on performance across the architectural innovation life cycle.

THEORY AND HYPOTHESIS DEVELOPMENT

Architectural innovation

In architectural innovation, while the technology behind each component is essentially unchanged, the linkages between components significantly change. Acquiring new architectural knowledge is critical to successfully deal with a new architectural innovation. Architectural knowledge is embedded in organizational information-processing routines, i.e., communication channel and information filters. Thus, one major concern of a firm pursuing a buy strategy in the face of a new architectural innovation is that the firm needs to develop new information-processing structures and routines to efficiently acquire new architectural innovation (Henderson & Clark, 1990). Developing new information-processing routines to get new architectural knowledge lead a firm and its supplier to face high coordination tasks. Another major concern is thus how efficiently to mitigate any potential knowledge exchange hazards arising from the high coordination (Nickerson & Zenger, 2004; Williamson, 1985).

Architectural Innovation Life Cycle and In-house Design

Early Period of a New Architectural Innovation: When a new architectural innovation emerges in the market, i.e., prior to the emergence of a dominant design, firms need to establish a history of actual trial-and-error experiences to understand the linkages between components in the new architecture (Henderson & Clark, 1990). However, because trial-and-error experiences are often not accumulated in the early period of a new architectural innovation's emergence to the market (Mayer & Argyres, 2004), firms are often tempted to generate new architectural knowledge with old information-processing structures, creating significant performance problems (Henderson & Clark, 1990). Thus, in the early stage of an architectural innovation's life cycle, switching to a new mode of learning by creating fresh information filters and communication channels is critical to efficiently creating new architectural knowledge.

Although *In-house External Component Design* has its own merits in reducing knowledge exchange hazards and creating unique model-specific knowledge, which is going to be explained in the next section, it may constrain firms from developing fresh information filters and communication channels. Since a firm's solution search for a new architectural innovation is routinized based on its own design, the firm may thus attempt to find solutions primarily with their own established organizational knowledge and routines. Moreover, *In-house External Component Design* helps firms prescribe at the outset the exact methods and procedures that suppliers should follow (Lacity, 2002). Firms with high *In-house External Component Design* are more likely to impose detailed process control (Tiwana & Keil, 2007) which can inadvertently decrease suppliers autonomy in ways that can potentially generate dysfunctional behavior. Imposition of prescribed processes can potentially be disruptive or incompatible with the established work practices, idiosyncratic routines, and internalized performance norms of the suppliers (McAfee, 2003). Once the processes to be followed are predefined by the firms, suppliers have lower discretion in interpreting and adjusting development methods in the specific context of the outsourced components. Excessive use of detailed process controls can further signal a lack of trust, which can motivate the suppliers to behave in ways that comply with the prescribed processes even if they are dysfunctional to the project objectives (Tiwana & Keil, 2007). Partner firms are thus likely to lose their motivation to voluntarily abandon old operating procedures and become actively involved in developing new procedures to acquire new architectural knowledge (Novak & Stern, 2008). Hence, *In-house Design* can prove a hindrance for firms in creating new communication channels and information filters in the early period of a new architectural innovation. And, *In-house External Component Design* is likely to inefficiently work for acquiring new architectural knowledge, which will negatively affect technological performances.

By contrast, pursuing a buy strategy without internalizing the design activity of outsourced components would allow firms to rapidly identify suppliers with effective capabilities in the new architectural innovation context. Such a strategy might prevent derailleur firms from becoming overly reliant on internal knowledge sets (Lei, Hitt, & Bettis, 1996; Leonard-Barton, 1992) and would pressure them into creating new information filters and communication channels to more rapidly acquire new architectural knowledge concerning the linkage between the derailleur and the freewheel (D'Aveni & Ravenscraft, 1994; Williamson, 1985). Thus, pursuing a buy strategy without internalizing the design activity of outsourced components can provide ample opportunities for successfully developing new architectural knowledge beyond internal efforts alone in the early period of a new architectural innovation (Brown & Eisenhardt, 1997; Spencer, 2003). These insights bring us to this study's first hypothesis.

> *Hypothesis 1: In-house External Component Design is likely to be negatively associated with technological performances in the earlier period of a new architectural innovation*.

Late Period of a New Architectural Innovation: Although cost competition becomes relatively important after the emergence of a dominant design, competition can continue to occur based on quality or performance aspects. Christensen et al. (1998) found, for example, that a rapid succession of disruptive innovations occurred in the disk-drive industry after the emergence of a dominant design. With the emergence of a dominant design, the realization of initial performance in the early period of a new architectural innovation motivates incremental innovation and improvement over the life cycle of that architecture (Adner & Kapoor, 2010). The high degree of component connectivity existing within a new architectural innovation can result in situations where the design of a new product architecture can not only differ across firms but also across product lines, even within the same firm (Sushandoyo & Magnusson, 2012; Ulrich, 1995). Thus, performance improvements over the life cycle of an architectural innovation require detailed and model-specific knowledge (Mayer & Argyres, 2004). A firm and its partner are required to engage in much trial-and-error experimentation to develop optimal linkages between components for specific product lines (Henderson & Clark, 1990; Ulrich, 1995). Such situations lead firms to face high-interaction solving-tasks and intensive coordination issues (Nickerson & Zenger, 2004; Teece, 1996).

These high coordination activities are likely to lead to relationship-specific engineering investments (Williamson, 1985), leaving firms vulnerable to knowledge exchange hazards (Nickerson & Zenger, 2004). *In-house External Component Design* allows firms pursing a buy strategy to develop capabilities in reducing knowledge exchange hazards and to create unique firm-specific routines in dealing with new architectural innovations. *In-house External Component Design* has been shown to help outsourcing firms establish procedures that its suppliers should follow (Lacity, 2002; Tiwana & Keil, 2007; Ulrich & Ellison, 2005) and enhances monitoring capabilities that help the firm track the progress of a supplier's investment and hinders any attempts to shirk responsibility. It aids firms in drafting effective contracts that can help the firm better avoid misunderstandings, define project milestones, and award proper incentives to discourage opportunistic behavior. Additionally, firms that design outsourced components in-house can provide suppliers with technical specifications and facilitate effective boundary-spanning activities (Tushman, 1977; Tushman & Katz, 1980), factors essential for creating unique boundary-spanning routines (Brusoni et al., 2001). This boundary spanning, in turn, helps firms develop model- and firm-specific routines (Simon, 1985) that facilitate the development of capabilities to integrate, reconfigure, and reengineer components to efficiently acquire new architectural knowledge. In the end, since the need for coordination increases over the life cycle of a new architectural innovation, the benefits of *In-house External Component Design* are likely realized during the later period of the new architectural innovation, which will positively affect technological performances.

By contrast, a firm that designed little or no outsourced components in-house would likely have difficulty in acquiring new architectural knowledge and reducing knowledge exchange hazards because its suppliers would possess the relevant design and manufacturing knowledge. Since the need for coordination increases over the life cycle of a new architectural innovation, the benefits of internalizing the design activity of outsourced components are likely to be realized after the emergence of a dominant design and would positively affect shifting performance. This line of reasoning provides the foundation for this study's second hypothesis.

Hypothesis 2: In-house External Component Design is likely to be positively associated with technological performances in the later period of a new architectural innovation.

U.S. ROAD BICYCLE DRIVE TRAIN MARKET

The U.S. road bicycle drive train market underwent a significant architectural shift due to a major architectural innovation (Fixson & Park, 2008). The drive train set consists of four components utilized when shifting gears on a bicycle – the shifter, derailleur, freewheel, and chain *[(only for reviewers) See Figure 1 in the supplemental material]*. When a bicycle rider shifts gears, a cable connecting the shifter to the derailleur is pulled, causing the derailleur to pull the chain onto the smaller or larger cogs of the freewheel *[(only for reviewers) See Figure 2 in the supplemental material]*. On a multi-speed bicycle, it is the derailleur mechanism that moves the bicycle chain between freewheel cogs *[(only for reviewers) See Figures 2 and 3 in the supplemental material]* during gear shifting. To test our advanced hypotheses, we created a longitudinal panel dataset from the U.S. bicycle drive train market from 1985 to 1995, focusing on derailluer firms' decisons regarding whether to readliy design the outsourced freewheel component.

Before 1985 when index shifting technology was introduced the market, gear shifting on a bicycle was very imprecise. Bicycle riders often had to rely on their own subjective judgment to determine if they had successfully shifted the chain from one gear to another. Late shiftings and friction noise were common occurrences. However, with the introduction of index shifting in 1985, bicycle riders no longer had to busily search for the proper gear but could simply push a button or ratchet on a shifter. The derailleur then automatically pulled the chain onto the freewheel cogs, providing a much improved shifting experience (*Bicycling,* March, 1987, pp.38-42). Index shifting technology was a remarkable innovation in the market to the extent that the CEO of Shimano U.S., a reputable bicycle drive train component manufacturer, mentioned that, "It took over the market so quickly that the companies that adapted to the rapid technological change thrived and the companies that moved slowly did not survive." Whether a bicycle's drive train incorporated the new index shifting technology became a landmark characteristic to judge if the bicycle was deemed modern or traditional.

Index shifting technology was a typical architecrual innovation. Prior to 1985, when the architectural innovation of index shifting technology was introduced, the architecture of the bicycle drive train was fairly standardized. Components made by one firm were interchangeable with components from another (*Bicycling,* March, 1987, pp.38-42). The new index shifting technology was quite different from the conventional drive train set. It required the use of indexed, not conventional, components, but the main concepts of each component did not significantly change. More importantly, the proper application of index shifting technology required firms to understand a new architectural linkage. In particular, properly designing the linakges between the derailluer and freewheel, called the *chain gap*, became critical for desirable shifting perfomrance. The chain gap is defined by the distance between the jockey-pulley of the derailleur and the freewheel, as measured along the chain *[(only for reviewers) See Figure 2 in the supplemental material]*). The chain gap in a conventional shifting system did not affect shifting performance to near the same extent as it did in an index shifting system. Actually, the term chain gap did not even exist prior to the advent of index shifting technology, implying that the gap between the derailleur and freewheel components was not a concern for firms under the old architectural paradigm. However, in index shfiitng systems, without an optimized chain gap, bicycle riders could not experience crisp gear shifting when using an index shifting system (p.108-128, Jan./Feb. 1988, *Bicycling*).

The optimal chain gap is primarily determined by the designs of the derailleur and freewheel components (for further details, see pp.1299-1303; Fixson and Park, 2008). A subtle change in a dimension or feature of the derailleur or freewheel would require an adjustment of the chain gap to maintain optimum shifting performance. If a firm had different derailleur or freewheel features than its rivals, simply copying a rival's optimized chain gap would not guarantee desirable shifting performance. Even the same derailleur company had varying chain gap dimensions in their different proprietary drive train set lines. In order to find the optimal chain gap, trial-and-error experimentation and integration of the freewheel and derailleur were required. Given that index shifting systems required new designs for new linkages between derailleur and freewheel, derailleur firms which outsourced freewheel had to decide whether to readily design the outsourced freewheel to provide the optimal chain gap for desirable shifting performance.

INDEX SHIFTING INNOVATION LIFE CYCLE

The theory of the innovation life cycle was originally presented by Utterback and Abernathy (1975) and Abernathy and Utterback (1978). According to this theory, the emergence of a *dominant design* ushers in new characteristics regarding innovation, firm strategy, organization, and the market into the industry life cycle (Utterback, 1994). In this study, we divide a new architectural innovation's life cycle into early and later time periods that are signified by the emergence of a dominant design.

We mark 1990 as the year in which a dominant design emerged in the bicycle drive train market for two reasons. First, although the emergence of a dominant drive train design was not a discrete event, its evolution rapidly gained momentum in 1988-1989; by 1990, the first model was introduced that incorporated all four key features – three concerning the derailleur and one involving the freewheel – of today's dominant design in derailleur and freewheel components. The most sophisticated modern derailleur included the following three key features: a two spring-loaded pivot, a slant parallelogram, and a Shimano-style cage geometry. The freewheel included one key feature – HyperGlide technology (Berto, 2005) – that was incorporated over time into the dominant design. Of course, innovations in bicycle drive trains continued at a furious pace. All these improvements, however, were achieved within the four fundamental design features that are now the dominant derailleur and freewheel designs. Second, under the theory of dominant design, many new firms will enter a market with variations of the new product in the early onset of an industry's evolution, which will generate an increase in the total number of firms in the market. However, the emergence of a dominant design eventually leads to an industry shakeout, resulting in a significant decrease in the number of firms in the market (Utterback, 1994). As predicted by the dominant design perspective, there were approximately 70 firms (both derailleur and freewheel firms) in the market before 1990, as shown in Figure 1. The wave of exits began in 1990, and the total number of firms significantly decreased to approximately 30 by 1995.

SAMPLE AND DATA

This study focused on the index shifting technology adoption of each individual derailleur/ freewheel set for each new drive train model. Our study's dataset included comprehensive information from 15 derailleur firms, 46 drive train sets, and 169 observations between 1985 and 1995. During this time, a primary source of information within the bicycle industry involved associated trade publications. *Bicycling* was one of the industry's leading trade publications and the periodical described not only bicycle and part prices in detail but also information regarding performance, index shifting mechanisms, component assembly instructions, and so on.

Bicycling also managed their own proprietary Super Spec Database. Through the generosity of former technical editors of *Bicycling*, we acquired a copy of the Super Spec Database. This database specified model titles, component names, and different freewheel manufacturers. For data source reliability, we also acquired an alternative database provided by another leading magazine, *Bicycle Guide*. With *Bicycle Guide*'s database, we obtained a similar size of sample firms, drive train sets, and observations. Other sources included the *Proceedings of the International Cycling History Conference*, the book *'Dancing Chain'*, and *Sutherland's Handbook for Bicycle Mechanics (6th ed.)* since these publications also facilitated an understanding of market and technological changes. In addition, the trade magazines *Bike Tech* and *Bicycle Guide* contained a wealth of technological information.

Data were also collected from interviews conducted during a field study between 2003 and 2008. Interview data were collected through semi-structured interviews with approximately 50 individuals, such as chief engineers, senior engineers, project (or technical) managers, and CEOs, including over 20 industry experts, most of whom had been associated with the industry for over two decades. The interviews were conducted either on-site at each company or via phone or email, with the typical interview ranging from two to three hours. Interviews with U.S and European companies were conducted in English whereas interviews with Japanese companies were conducted in Japanese. In its data collection process, this study compiled an extremely thorough data set.

MEASURES

Dependent Variables. This study used *Shifting Timing* and the number of missed shiftings *(No. of Missed Shiftings)* as measures for shifting performance. *Bicycling* annually tested various drive trains with specialized test equipment. Since bicycle trade magazines were popular sources of information, derailleur firms and trade publication editors would argue over test results that did not put a particular company in a favorable light. Derailleur firms would provide detailed instructions regarding their index shifting drive train component assembly to *Bicycling* to provide assembly instructions for optimal shifting performance. In addition, specialized test tools were used to randomly shift gears multiple times within a certain time duration.

In *Bicycling*'s tests, each derailleur was run through a full set of 16 shifts. *Shifting Timing* was rated according to early and late shifting. Early-shifting derailleurs changed gears within approximately a 15-teeth interval of the freewheel cog, whereas late-shifting derailleurs typically changed gears within a 30-teeth (or more) interval of the freewheel cog *[(only for reviewers) See Figure 7 in the supplemental material]*. Early-shifting systems generated less sliding friction between the chain and the freewheel. A late-shifting rear derailleur took more lever force and would frequently skip a gear or lead to missed shiftings. Essentially, the earlier the shifting occurred, the better the shifting performance. *Bicycling* was able to precisely record the start and end point of each gear shift. For each drive train model within a specific year, *Bicycling* recorded shifting timing on a rating scale that ranged from 1 to 10, with 10 as the highest rating. This study used these performance scores but normalized them according to market segment. We also used the total number of missed shiftings during a full set of 16 shifts (*No. of Missed Shiftings)* as another dependent variable.

Independent Variable. To determine whether the outsourced freewheel component for a given drive train set was designed in-house, we initially created a rudimentary history of *In-house External Component Design* (*In-house ExtComp Design*) derived from technical instructions provided by *Bicycling*. As explained above, derailleur firms provided detailed instructions on how to assemble components for optimal shifting performance. Based on these instructions, we developed a preliminary understanding of whether a firm was capable of readily designing outsourced freewheels for a given drive train set. However, this compiled history might still be incomplete or problematic because the printed instructions might be based on the knowledge possessed by external suppliers rather than the firms themselves. We therefore had to confirm whether firms designed outsourced freewheels in-house via expert interviews with individuals who had at least 15 years of professional experience. Our analysis of *In-house External Component Design* was conducted directly with two or three chief engineers from each firm we interviewed extensively. When required, we also received additional assistance from senior engineers or technical specialists. To enhance veracity, subjects were given an outline of the research study and an explanation of key terms. They were also given a list of questions related to the design of freewheel components within their respective drive train sets. The questions focused principally on objective information to minimize any response bias. To assess *In-house External Component Design*, we asked whether the design of the outsourced freewheel was actually created in-house for each drive train set. Finally, we asked respondents to provide *diagram descriptions (product drawings)* that displayed how they designed the freewheel *[(only for reviewers) See Figures 5 and 6 in the supplemental material]*. Most drive train sets exhibited agreement between the interviewees' answers and the diagrams, in addition to *Bicycling*'s instructional explanations. Regarding conflicting cases, we asked our interviewees for written and verbal comments for clarification. If an explanation was unclear, we removed it from our data pooling. Based on these interviews and diagrams, *In-house External Component Design* was measured as '1' if a firm designed outsourced freewheels in-house and '0' if it did not.

Control Variables. The complexity of the derailleur (*Derailleur Complexity*) could directly impact shifting performance. As explained earlier, the most sophisticated derailleurs included three key features: a two spring-loaded pivot, a slant parallelogram, and a Shimano-style cage geometry (Berto, 2005). Thus, the complexity of the derailleur was determined by whether it included one, two, or all three of these features. We rated derailleur complexity as '0' if it included none of the three characteristics, '1' if it included only one of the three, '2' if it included two of the three, and '3' if it included all three features. Additionally, we included the number of freewheel-associated patents (*Freewheel_Patents*). We asked industry experts who possessed extensive development experience with drive train components to identify the most prominent technology subclasses associated with the freewheel. These experts identified the patent subclasses 474/78-297 and 475/269-330 as the dominant patent subclasses for all derailleur- and freewheel-specialized firms. This variable was operationalized as the number of freewheel and freewheel-related patent applications filed by a firm over the three years preceding the firm's commercialization of a new drive train set. *Product Differentiation* can also affect performance. In the bicycle market, product differentiation was heavily dependent upon bicycle price. Thus, we measured product differentiation by locating drive train sets within bicycle pricing segments. *Bicycling* magazine provided segments by pricing levels. We categorized *Product Differentiation* as '0' if a derailleur/freewheel set targeted the low-price market, '1' if it targeted the mid-price market, and '2' if it targeted the high-price market. *Sourcing Duration* was also included because it can affect product performance (Gulati, 1995; Hoetker, 2006). This variable was defined as the length of time (in years) that a firm pursued its current outsourcing strategy. *Firm Size* was measured by market share in *Bicycling's* Super Spec Database, and *Firm Age* was measured as the length of time (in years) that a firm produced derailleur components. Finally, derailleur firms might have different freewheel suppliers for different drive train sets, which could ultimately result in different performance levels. Therefore, this study also controlled for the number of suppliers used by each firm in a given year (*Number of Suppliers*). For our 15 sample firms, the variable *Firm Dummies* was used to capture any unmeasured heterogeneity across panels.

Instrumental Variable: This study included *Instrument for P_In-house ExtComp Design* as an instrumental variable, which indicates the degree to which a firm internally designed freewheel components used in other drive train sets (and not the given set). We explain why we used this variable in the *Analysis* section.

ANALYSIS

Empirically testing the impact of internalizing the design activity of outsourced components on performance is not a simple problem due to endogeneity (self-selection or invisible factor) concerns (Hamilton & Nickerson, 2003). For example, firms performing *In-house External Component Design* may possess unique production capabilities that are unobservable in certain models, which might make *In-house External Component Design* a profitable and attractive choice. Contrastingly, if firms without *In-house External Component Design* suddenly decide to internalize the design activity of outsourced components, they would initially be less successful than firms that originally performed *In-house External Component Design*. Given such possibilities, we estimate the following two models.

$$Performance = \alpha_1 + \beta_1{*}Control\ Variables + \beta_2{*}In\text{-}house\ ExtComp\ Design + \varepsilon_1 \quad (1)$$

$$P\_In\text{-}house\ ExtComp\ Design = \alpha_3 + \beta_4{*}Control\ Variables + \beta_5{*}Instrumental\ Variable\ (Instrument\ for\ P\_In\text{-}house\ ExtComp\ Design) + \varepsilon_2 \quad (2)$$

$$Performance = \alpha_{26} + \beta_7{*}Control\ Variables + \beta_8{*}P\_In\text{-}house\ ExtComp\ Design + \varepsilon_3 \quad (3)$$

It should be explained that the estimations shown in Equation (1) do not consider the endogeneity of *In-house External Component Design*, thus leaving room for biased estimates (Shaver, 2005). For example, not considering unobservable firm-specific effects impacting both *In-house External Component Design* and performance would give rise to endogeneity issues because the error term (ε_2) would be correlated with the *In-house External Component Design* variable in Equation (2). Shaver (2005) suggests that employing a two-stage least squares estimation (2SLS) may resolve endogeneity concerns. Such a method would utilize the predicted values of *In-house External Component Design* (from Equation (2)) to determine its effect on performance instead of utilizing actual values from Equation (1). In addition, this method must incorporate instrumental variables that impact *In-house External Component Design* but not shifting performance directly; this instrumental variable thus should not be included in Equation (3).

Our instrumental variable was assessed based on the internalization of freewheel design activity for ***other*** drive train sets. In their investigation of the automotive industry, Novak and Stern (2009) showed that the degree of vertical integration in any one automobile system was sensitive to the degree of vertical integration in other automobile systems. They also discovered that system-specific returns to vertical integration for one system should have a spillover effect onto other systems within the same automobile model. In much the same way, firms that internalized the freewheel design activity for other drive train sets may likely possess specific capabilities that make designing the freewheel component in-house a profitable decision. As expected, many derailleur firms tended to design freewheel components across different drive train sets in-house. Keeping in mind that the degree to which firms internally designed freewheel components for other drive train sets should not directly influence the performance of a given drive train set, accounting for the extent to which firms internalized the freewheel component design activity for other drive train sets (*Instrument for P_In-house ExtComp Design*) seems fitting.

Next, this study pooled the yearly product-/firm-level data and estimated a single model in which the dependent product-level variables were defined as *Shifting Timing* and *No. of Missed Shiftings*. Although the unit of analysis was each individual drive train set, the independent variables included both product- and firm-level variables. Thus, we ran a generalized Hausman (1978) specification test for fixed vs. random effects, and the fixed-effect model dominated. Finally, we used the Wooldridge (2002) test to check for autocorrelation by using "*xtserial*" in

STATA. The test result could not reject the null hypothesis of no first-order autocorrelation. To be free from AR(1) autocorrelation, we used "*xtregar*" in STATA.

RESULTS

Table 1 presents the summary statistics and correlation coefficients for the variables in our study. The purpose of the first-stage selection model in Model 1 of Table 2 is to generate the predicted value of *In-house External Component Design*. Not surprisingly, *Instrument for P_In-house ExtComp Design* proved significant (+0.325, *p<0.01 in Model 1*), which indicated that firms that designed the freewheel components for other drive train sets were more likely to design freewheels in-house for the drive train set investigated.

The second-stage performance models are shown in Models 2 through 7. Models 2 and 5 are concerned with whether *In-house External Component Design* significantly affected shifting performance without considering the architectural innovation life cycle. *In-house External Component Design* was positive and significant in Model 2 (+2.826, *p<0.01*) and was negative and significant in Model 5 (-1.196, *p<0.05*). These results suggest that readily designing the outsourced freewheel in-house was likely to improve shifting timing and decrease the number of missed shiftings, respectively, which support the arguments in the literature (Kapoor & Adner, 2012; Park & Ro, 2011).

Table 1: Descriptive Statistics and Correlations

		1	2	3	4	5	6	7	8	9	10
1	Shifting Timing	1.000									
2	No. of Missed Shiftings	-0.470	1.000								
3	In-house ExtComp Design	+0.266	+0.002	1.000							
4	Derailleur Complexity	-0.050	+0.046	+0.041	1.000						
5	Freewheel_Patents	-0.037	-0.070	-0.005	-0.061	1.000					
6	Product Differentiation	+0.036	-0.058	+0.025	+0.032	+0.050	1.000				
7	Sourcing Duration	+0.050	-0.045	-0.153	-0.003	-0.078	+0.014	1.000			
8	No. of Suppliers	+0.032	-0.021	+0.146	-0.007	-0.115	-0.033	-0.020	1.000		
9	Firm Size	-0.079	+0.001	+0.004	-0.010	+0.064	+0.026	+0.036	-0.030	1.000	
10	Firm Age	+0.059	-0.002	+0.141	-0.012	+0.041	+0.015	-0.025	-0.018	+0.398	1.000
	Mean	4.989	3.817	0.316	2.206	2.790	0.876	6.731	1.951	0.067	23.64
	S.D.	2.403	1.813	0.465	1.132	2.654	0.837	2.632	0.829	0.138	16.43
	Max	10	9	1	3	8	2	12	3	0.700	49
	Min	0	0	0	0	0	0	1	1	0.001	1

Regarding Hypothesis 1 in terms of *Shifting Timing*, the *In-house External Component Design* coefficient of the earlier period in Model 3 is negative but not significant (-1.437), which suggests that designing the outsourced freewheel in-house may not significantly affect *Shifting Timing*.

In terms of *No. of Missed Shiftings*, however, Hypotheses 1 is strongly supported. The *In-house External Component Design* coefficient of the earlier period in Model 6 is positive and significant (+2.729, *p<0.05*), which suggests that internalizing the design activity of the outsourced freewheel was likely to increase the number of missed shiftings. In other words, having outside suppliers design the freewheel component was more likely to decrease *No. of Missed Shiftings*.

Hypothesis 2 is strongly supported with both measures of technological performance. The *In-house External Component Design* coefficient of the later period in Model 4 is both positive and significant (+1.953, $p<0.1$), which suggests that internalizing the design activity of the outsourced freewheel was likely to significantly improve *Shifting Timing*.

Regarding *No. of Missed Shiftings,* the *In-house External Component Design* coefficient of the later period in Model 7 is negative and significant (-2.950, $p<0.01$), which suggests that designing the outsourced freewheel in-house was likely to significantly decrease the *No. of Missed Shiftings*.

Table 2: Estimation Results

	1st Stage (In-house Design)	2nd Stage: Shifting Timing (Higher values denote better performance)			2nd Stage: No. of Missed Shiftings (Lower values denote better performance)		
		All	Earlier	Later	All	Earlier	Later
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
P_In-house ExtComp Design		+2.826***	-1.437	+1.953*	-1.196**	+2.729**	-2.950***
		(0.557)	(1.205)	(1.042)	(0.549)	(1.049)	(0.986)
Instrument for P_In-house ExtComp Design	+0.325***	--	--	--	--	--	--
	(0.012)						
Derailleur Complexity	+0.029**	+0.053	-0.336	+0.150	+0.026	-0.245	-0.406
	(0.012)	(0.192)	(0.523)	(0.259)	(0.197)	(0.521)	(0.251)
Freewheel Patents	+0.013	-0.107	-0.034	+0.095	-0.143	+0.254	-0.588***
	(0.009)	(0.194)	(0.561)	(0.205)	(0.181)	(0.491)	(0.182)
Product Differentiation	+0.018	-0.105	-0.137	+0.050	+0.079	+0.206	+0.245
	(0.017)	(0.295)	(0.634)	(0.519)	(0.287)	(0.553)	(0.483)
Sourcing Duration	-0.003	+0.076	-0.198	+0.175	-0.036	+0.053	-0.110
	(0.006)	(0.107)	(0.371)	(0.145)	(0.106)	(0.349)	(0.137)
No. of Suppliers	-0.029**	+1.129	+2.018**	-0.006	+0.065	+0.365	-0.064
	(0.014)	(0.811)	(0.808)	(0.484)	(0.271)	(0.736)	(0.461)
Firm Size	+0.013	-0.258	-4.194	-7.538	-2.745	+5.615**	-6.154
	(0.276)	(8.232)	(27.98)	(9.412)	(7.820)	(2.672)	(8.601)
Firm Age	+0.044***	+0.142	-0.484	+1.383**	-0.307	+0.203	-0.517
	(0.007)	(0.236)	(0.799)	(0.593)	(0.195)	(0.813)	(0.514)
Firm Dummies	Included	Included	Included	Included	Included	Included	Included

Constant	-1.029***	-1.033	+8.187	-3.391	+12.74***	-7.224	+2.459*
	(0.149)	(3.706)	(16.11)	(1.316)	(3.632)	(14.53)	(1.273)
N	169	169	78	91	169	78	91
R^2	0.802	0.259	0.325	0.524	0.117	0.544	0.604
F Statistic	106.19***	4.55***	1.08	4.97***	1.74	2.69**	6.89***

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

DISCUSSION AND IMPLICATIONS

Given the presumption of modularity scholars (Brusoni et al., 2001; Park & Ro, 2011; Ulrich & Ellison, 2005) and technology management scholars (Kapoor & Adner, 2012) to underscore the positive role of *In-house External Component Design* in dealing with a new architectural innovation, the purpose of this study is to elaborate on this presumption by incorporating the concept of the innovation life cycle. This study suggests that the most prudent course of action for a firm facing a new architectural innovation is to leave the design activity of outsourced components in the hands of its suppliers during the initial emergence period of an architectural innovation, and then later switch to retaining *In-house Design* after a dominant design emerges. By having external suppliers design outsourced components during the early stages of an architectural innovation's emergence, firms can embark on new knowledge creation and switch to new modes of learning by creating fresh information filters and communication channels critical for successfully generating new architectural knowledge. And by internalizing the design activity of outsourced components during the later stages of an architectural innovation's emergence, after the advent of a dominant design, firms can address intensive coordination needs associated with the new architectural innovation.

When considering a new architectural innovation as an endogenous variable, the presumption of earlier studies regarding the positive role of internalizing the design activity of outsourced components (e.g., Park & Ro, 2011) may yet be correct. When a firm addresses the high interdependence issues resulting from an architectural innovation, *In-house External Component Design* may be closely associated with higher performance. However, when considering an architectural innovation as an exogenous variable at the industry level (i.e., where a new architectural innovation emerges in the market), the generally accepted arguments of earlier studies for the preference of *In-house External Component Design* when facing architectural shifts may be somewhat over-simplified. Earlier, we argued that this result might ensue because the benefits of *In-house External Component Design* will vary over the life cycle of the new innovation after a new architectural innovation emerges in the market. This study may be the first to investigate the performance implications of internalizing the design activity of outsourced components across the life cycle of a new architectural innovation. Our results point to the need for more careful theoretical and empirical investigation of this generally accepted presumption, particularly given its theoretical and managerial effects (Brusoni et al., 2001).

Since the earlier presumption might not always hold, this study accordingly suggests revisiting other industries in which the role of *In-house External Component Design* is apparently positively related to performance. For example, in the DRAM market, a recent study by Kapoor and Adner (2012) discovered conflicting results regarding the impact of *In-house External Component Design* on performance. In the DRAM industry, the mask essentially determines the DRAM chip design. Among firms that outsourced mask production, the greater a firm's mask knowledge, the faster its time to market for a new product generation. However, with respect to the resist knowledge for firms that outsourced resist production, these authors did not find any support for the positive role of the resist knowledge on performance. Testing this role by considering the innovation life cycle might possibly lead to more insightful results.

Although our study contributes to the understanding of the relevant literature regarding the role of *In-house External Component Design*, it does not explicitly claim to provide reasons for why certain firms internalized the design activity of outsourced components and why others did not. Additional research is required to diagnose firms' different decisions regarding *In-house External Component Design*. For example, prior experiences with architectural innovations could be an exploratory factor. Through prior experiences, firms may understand the significance of *In-house External Component Design*, and may thus be more likely to retain it. However, prior architectural innovation experiences can also affect performance. Since internalizing the design activity of outsourced components may be a prerequisite for improving performance in pursuing a buy strategy (Takeishi, 2002; Zirpoli & Becker, 2011), prior experiences may be a moderating or mediating factor in the relationship between *In-house External Component Design* and performance. Thus, investigating the interplay between *In-house External Component Design*, prior architectural innovation experiences, and performance would be a valuable research topic. Finally, because it is rare to investigate the interplay between the internalization of the design activity of outsourced components and the innovation life cycle in any industry, the generalization of our findings in other contexts should be explored.

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