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RESEARCH ARTICLE

When and how to shift gears: Dynamic trade-offs among adjustment, opportunity, and transaction costs in response to an innovation shock

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***Research Summary*:** This study explores incumbent responses to the architectural innovation shock of index shifting in the bicycle component industry. Incumbents differed by when they imitated and by organization of production—some integrated while others outsourced components—and many of these decisions changed over time, which are not explained by extant theory. This paper develops a theory that predicts timing of imitation and organizational choice for component manufacturing that highlights a dynamic trade-off among adjustment, opportunity, and transaction costs that explains timing of imitation, organizational structure of component manufacturing, and changes in organizational structure. Empirical analysis finds support for a fundamental trade-off among these costs in response to an innovation shock.

***Managerial Summary*:** An innovation shock presents managers both an opportunity to reposition and gain advantage against competitors and creates competitive pressure to do so. When and how should firms respond to such shocks? This paper develops a comparative approach to help managers decide when and how to imitate an innovation shock. The paper recommends comparatively assessing adjustment costs, opportunity costs of moving late, and initially outsourcing to imitate quickly even though doing so may be costly and problematic over the long-run. The paper also predicts when firms should integrate to produce more efficiently. These findings are illustrated through the introduction and adoption of index shifting in the sport bicycling market from 1980 through 1995.

KEYWORDS

adjustment costs, dynamic trade-offs, innovation shock, opportunity costs, transaction costs

1 | INTRODUCTION

In 1985, Shimano Inc. introduced *index shifting* to the sport-bicycle world, an architectural innovation (Henderson & Clark, 1990) widely acknowledged as a substantial shock to the bicycle components industry. Index shifting refers to a highly coupled set of bicycle gear-shifting components—a shifter, derailleur, chain, and freewheel—that interact as a system, more tightly coupled than prior component set technologies (*Bicycling*, March/1987, p. 38; September/1988, p. 8; December/1989, pp. 96–100). Whereas the prior technology required the rider to "feel" how far to move a shift lever to change gears using these components, index shifting made it easy and precise for the rider to "click" from one gear to another, which greatly improved shifting efficiency. Some innovations in the bicycle component industry have little impact on competition. Not index shifting. Within a decade of this shock, all competitors had adopted index shifting.

As might be expected, some competitors adopted index shifting quickly, others with delay, and some not until nearly a decade had elapsed. A noticeable aspect of these adoptions is that some imitators initially outsourced production of components while others vertically integrated. Yet, many of these initial organizational decisions about production of the same components were later reversed over the decade. With competitors introducing multiple component sets as time progressed, the organizational decisions varied not only over time but also over the mix of each firm's component set. In an industry in which product launches are transparent, highly publicized, and known instantly by customers and competitors and with the technical dominance of index shifting over other products so clear, why did firms choose to imitate at different points in time? When and why did these firms call upon outsourcing versus vertical integration and why were many early decisions later reversed? Were these decisions to imitate, organize transactions, and later reverse organizational choices mistakes, a reflection of passive adoption, or strategic?

The economic, organizational, and strategic management literatures offer several possible explanations. Delayed imitation may reflect a diffusion that correlates with the varying levels of adjustment costs or organizational inertia: low adjustment cost firms respond faster or older and bigger incumbents, for example, are slower to adapt than younger and more agile competitors (Moch & Morse, 1977; Sorensen & Stuart, 2000). With respect to organizational choices, perhaps initial organizational choices were poor decisions that later needed to be corrected (e.g., Williamson, 1985), the component sets became more or less decomposable over time leading to shifts in efficacy of organizational alternatives (e.g., Argyres & Bigelow, 2010), or firms generally outsourced to speed up their imitation (Powell, Koput, & Smith-Doerr, 1996; Rothaermel & Deeds, 2004). A casual exploration of the data suggests none of these explanations holds much purchase over the time frame of market adoption. Entry order does not strongly negatively correlate with standard proxies for adjustment cost or organizational inertia like age and size. Most firms were old and had deep experience with both vertical integration as well as outsourcing of components, which suggests that poor organizational decisions are unlikely or, at best, should be small in number. The tight coupling of a component set remained a key feature of index shifting, which means that the level of decomposability did not change over time. Some firms outsourced components whereas others vertically integrated indicating that at least not all firms outsourced to accelerate imitation. What then explains firm-specific timing of imitation and changing organizational choices for incumbents in the sport-bicycle component industry?

In this paper, we develop theory to predict the timing of imitation (when) and the organizational choice for component manufacturing (how) that highlights a dynamic (i.e., time-varying) trade-off among adjustment, transactions, and opportunity costs (Argyres, Bigelow, & Nickerson, 2015;

Argyres, Mahoney, & Nickerson, 2018; Nickerson & Silverman, 2003). Our theory begins with the generalization that because of path dependencies of prior decisions, firms vary in their adjustment costs with respect to imitating the first mover, ceteris paribus. As a baseline prediction, firms with low adjustment costs will imitate quickly whereas those with high adjustment costs will be laggards. That said, we argue that firms may be able to strategically and substantially lower their adjustment costs by accepting the trade-off of high expected transaction costs. In particular, a firm may choose to inefficiently organize a transaction in the short-run if doing so substantially accelerates imitation. The incentive to trade-off transaction costs to lower adjustments costs will be greater for those firms that face higher opportunity costs (e.g., the rapid loss of market share) from the failure to quickly imitate especially when remaining in their established pre-shock market positions is economically infeasible. Firms without high opportunity costs from failing to move quickly will gain little from making this trade-off and therefore will imitate—often with substantial delay—with transaction cost economizing organizational choices.

Once adjustment cost concerns for early imitators lessen because moves have been made, transaction cost concerns will likely dominate for early as well as late imitators as competitive intensity increases. In the former case, early imitators will be increasingly likely to reconfigure the organization of their transactions over the long-run in accordance with transaction cost predictions. In the latter case, late imitators will be increasingly likely to choose at the time of imitation transaction cost economizing organizational structures. In essence, shocks lead to a dynamic interplay among adjustment, opportunity, and transaction costs that effect repositioning decisions that none of these theories predict alone.

We explore these theoretical predictions with a comprehensive longitudinal study of the U.S. bicycle components industry for the decade following Shimano's index shifting innovation shock. We identify 43 firms that produce derailleurs, most of which manufactured the component internally (35 derailleur firms). For each firm, we track when they imitated in response to the shock, and the make versus buy decision over time for each component in a set, *sans* derailleur. As directly measuring adjustment, opportunity, and transaction costs is notoriously difficulty, we construct variables as proxies for each theoretical construct and predict the effects of these proxies on the nature and timing for imitation and sourcing decisions, focusing especially on knowledge-based resources, and on the organization of each component, within each set, for each firm. Using a variety of econometric models, we are unable to reject our principal predictions. Coefficient estimates are consistent with the prediction that early imitators strategically organize to lower adjustment costs by accepting higher expected transaction costs especially when opportunity costs for slow imitation are high. Indeed, for these early adopters our proxies for transaction costs are statistically insignificant. For both late adopters and early adopters in the second half of the decade, our coefficient estimates tell a substantially different story; estimated coefficients are statistically significant and consistent with economizing on transaction costs when imitating.

Our paper adds value to the economics, organization, and strategy literatures by building on Argyres et al. (2018) and empirically assessing the trade-off among adjustment, transactions, and opportunity costs after an innovation shock. This theory can help explain prior research that indicates why some firms choose inefficient organizational modes prior to the emergence of a dominant design (Argyres & Bigelow, 2007) and why other firms are late to imitate an innovation shock (Silverman, Nickerson, & Freeman, 1997). Providing proxies for adjustment costs, transaction costs, and opportunity costs allows practitioners to assess when and how to strategically respond to innovations based on an assessment of industry participants. As a result, we believe that this paper contributes to the literatures on strategic responses to innovation shocks in the context of adjustment and transaction costs that collectively may help practitioners decide when and how to respond to innovation shocks.

Our paper continues by offering a background on transaction costs as well as on adjustment costs and imitation in the context of innovation shocks. We then develop our theory and specific predictions. After introducing the context of the bicycle component industry and index shifting, we describe measures and proxies, econometric methods, and report results. We discuss these findings and conclude the paper.

2 | BACKGROUND

When and how do firms respond to innovation shocks? In order to explore this question, we begin by visiting the definition of an innovation shock. Argyres et al. (2015) define an innovation shock as the introduction by a firm of a new product (or service) that stimulates a substantial surge and acceleration in demand for that product. An innovation can be based on a new configuration of attributes that might include incremental or radical innovations, and might include components developed in-house or by other firms. The critical factors that identify the innovation shock are that the new product represents a novel *composition* of elements (even if many individual elements already exist in rival products) and that it stimulates a large, unanticipated surge in demand (2015, p. 217). Such a shock can occur any time and can range from one that does not disrupt competition because it is easy, quick, and inexpensive to imitate to one that is disruptive, which makes imitation difficult, slow, and expensive to followers.

Well known is that technological breakthroughs, which are one kind of shock (Argyres et al., 2015), can be disruptive to market participants generating periods of uncertainty as firms respond (e.g., Anderson & Tushman, 1990). This uncertainty can leave incumbent positions vulnerable (e.g., Christensen, 1997) and dismantle the advantage of incumbent knowledge (e.g., Kogut & Zander, 1992; Leonard-Barton, 1992; Sosa, 2013). Also, shocks create opportunities for incumbents to overtake rivals (Mowery & Nelson, 1999) and leverage existing capabilities, especially knowledge-based capabilities, rendering them more formidable competitors over time (Helfat & Raubitschek, 2000; Tripsas, 1997). While these literatures indicate that shocks can disrupt competition and create changing fortunes for firms in a market, the extant research fails to offer specific ex ante predictions about when and how firms will respond to the shock.[1]

Assuming that an innovation shock is at least somewhat disruptive to market participants, we can explore a variety of literatures with which to make predictions. Most approaches to explaining when and how firms respond to innovation shocks build upon the idea of adjustment costs. Adjustment costs have a long history in macroeconomics that goes back to Lucas (1967). He developed a seminal theory of aggregate market supply assuming that firms' response to exogenous shocks will not be instantaneous because of frictions internal to the firm. Although adjustment costs became an important concept theoretically and empirically in macroeconomics, Lucas (1967, p. 322) advised against modeling firm-specific adjustment costs because doing so would make deriving testable implications for movements between equilibria of aggregate supply and demand much more difficult (for a broader discussion see Argyres et al., 2018). Without admitting firm specific adjustment costs, all

[1]Without doubt the notion of an innovation shock relates to the literature on dominant designs (e.g., Anderson & Tushman, 1990; Jovanovic & MacDonald, 1994; Klepper, 1996; Utterback & Abernathy, 1975) especially as the predicted market life-cycles imply that innovation shocks of various kinds occur through the history of the market. We do not develop this relationship because the dominant design literature neither focuses on specific shocks nor develops theory that predicts how and when specific firms respond to an innovation shock.

firms are predicted to move together in response to shock, which means macroeconomic findings provide little insight for our purpose.

Organizational demographers also theorize about adjustment costs through the concepts associated with organizational inertia. They theorize that organizational inertia slows adaptation as organizations seek legitimation and engage in competition within a defined population. While many factors of inertia have been explored, organizational age and size are central attributes. Research shows that organizational age, which also is a proxy for incumbency (e.g., Carroll & Hannan, 2000; Klepper, 1996), and size leads to older and bigger incumbents being buffered from population pressures implying that they adapt more slowly than younger and more agile competitors (Moch & Morse, 1977; Sorensen & Stuart, 2000). Although size can be viewed as an incumbent buffer from the disruptive effects of shocks (Amburgey, Kelly, & Barnett, 1993; Carroll & Hannan, 2000), the reverse also has been found in relation to size in some organizational populations (Le Mens, Hannan, & Polos, 2015).

Unfortunately, population ecology research explores the vital rates of entry and exit, and in some instance resource partitioning (Carroll, 1985; Dobrev, Kim, & Carroll, 2002), and not organizational adaptations to innovation shocks. Nonetheless, using the key findings of population ecology to predict organizational responses might suggest that the more disruptive an innovation shock to a firm's existing resource profile, the more organizational inertia should create variance in the response of incumbents with larger firms increasingly lagging responses by smaller firms. The effects of age on adaptation are less clear; although, relying on the preponderance of findings in the literature suggests that older organizations will likely adapt more slowly (Barnett & Carroll, 1995; Sorensen & Stuart, 2000).

The notion of adjustment costs has a rich history throughout the strategy literature. While adjustment cost terminology is not always used in various theories, strategic management scholars nonetheless have relied on various notions of adjustment costs to explain mechanisms that produce sustainable sources of competitive advantages. For instance, followers may find it costly and time consuming to (a) imitate capabilities, resources, and assets (Barney, 1991; Helfat & Eisenhardt, 2004); (b) access human capital and managerial expertise (Hitt, Bierman, Shimizu, & Kochhar, 2001; Penrose, 1959); (c) acquire and absorb knowledge (Cohen & Levinthal, 1990; Grant, 1996; Kogut & Zander, 1992) or over-come lock-in from old knowledge (Leonard-Barton, 1992); (d) overcome sunk costs or prior and credible commitments (e.g., Ghemawat, 1991; Ghemawat & Costa, 1993), (e) invest in asset specificity (e.g., Williamson, 1985); (f) overcome mobility barriers and time lags and time compression diseconomies (e.g., Dierickx & Cool, 1989; Pacheco-de-Almeida & Zemsky, 2007). In each one of these theories, various classes of adjustment costs are implicated as the reason why competitors are impeded from immediately and costlessly imitating thereby maintaining the privileged profit position of the progenitor of the innovation shock. Adjustment costs therefore represent a natural perspective in strategic management to theorize how variations in these costs may advantage or disadvantage firms in responding to an innovation shock.

Two research streams have begun to incorporate adjustments costs into models of repositioning. In examining to which positions firms might reposition, Menon and Yao (2017) argued for the need to take into account the costs of adapting to change, which can differ by firm. They labeled these adjustment costs "repositioning costs" and claim such costs have been largely underdeveloped in the literature. An important caveat in their theory is why a firm might reposition. Argyres et al. (2015, 2018) provide answers to why reposition by arguing that innovation shocks, along with supply, demand, and regulatory shocks, can give rise to the need for repositioning in the form of entry, exit, imitation, and differentiation. They argue that adjustment costs for repositioning are not only firm specific but also potentially specific for each origin–destination pairing as adjustment costs are likely path dependent. The primary implication from Argyres et al. (2018) is that followers undertake a comparative analysis with respect to competitors and each possible repositioning in order to generate useful predictions. For instance, a firm may find it unwise to reposition based on its lowest adjustment cost alternative if other competitors achieve the new position with lower cost or arrive first thereby capturing economies of scale or scope.

Theorizing within specific contexts about the effect of adjustment costs on when and how firms adapt in response to a shock must account for two challenges. First, precise measurement of adjustment costs is difficult if not impossible to measure ex ante. Without the availability of cardinal measures that enable calculation of optimal strategies, researchers must identify ordinal proxies that can be used to compare across firms and repositioning alternatives. A challenge for theory and empirical analysis is that such proxies can be unique to a specific context.

Second, firms may attempt to act strategically to lower their adjustment costs to jockey for capturing a more attractive position or at least undermine a first mover's advantage by imitating quickly. Such strategic moves are more likely when rents can accrue to first or early movers or a position can be foreclosed to late movers when barriers to entry build rapidly. Both situations suggest that strategic action to lower adjustment costs, even if such actions are costly, is more likely when opportunity costs are high.

One of the principle ways in which firms can strategically influence adjustment costs is through organizational structure (Kapoor & Adner 2012; Nickerson & Zenger, 2004). Make versus buy is implicated in this situation. Transaction cost economics predicts that when coordinated adaptation associated with asset specificity is needed (Williamson, 1985, 1996), vertical integration can offer adaptation advantages with respect to disturbances within the transaction. Conversely, outsourcing favors autonomous adaptation and is appropriate when asset specificity is lacking (Williamson, 1985, 1996). Yet, if a firm wants to move faster to lower adjustment costs, it may have to confront adopting an organizational form that presents a noneconomizing mismatch with transaction cost predictions (Argyres et al., 2018). For instance, several scholars (Alcacer & Oxley, 2014; Holcomb & Hitt, 2007; Mowery, Oxley, & Silverman, 1996) advocate outsourcing to learn faster; but doing so can be problematic from a transaction cost perspective when co-specialization is involved. To suggest that firms may *knowingly* incur transaction costs is at odds with Williamson's prescription that economizing is the best strategy (Williamson, 1991).

Drawing on these ideas, Argyres et al. (2018) argue that a trade-off can exist between transaction costs and adjustment costs and be affected by the magnitude of the opportunity costs at stake. In the presence of potential first-mover advantages and/or winner-take-all market conditions, the opportunity costs of delayed response can rise substantially. In such situations, firms with high comparative adjustment costs are likely to strive to reposition ahead of rivals because the opportunity costs of not doing so is great, even if doing so incurs high transaction costs. The potential benefit from alacrity of response and potential first-mover gains versus mal-adaptation from high transaction from misalignment will depend on the specifics of the situation. Therefore, specific proxies need to be worked through with respect to the nature of the innovation shock, market, and competitive environment.

3 | THEORY

A wide swath of research acknowledges that imitating an (architectural) innovation can be costly (e.g., Ethiraj, Levinthal, & Roy, 2008) (e.g., Henderson & Clark, 1990). A general and well-known principle in economics, strategy, and organization theory is that delays in imitation are related to adjustment costs: the larger the adjustment costs, the longer the delay in imitation (Argyres et al., 2015). Like finding that the "devil is in the details," so too must distinct aspects of the context of a situation be explored to unpack the specific details of adjustment costs in response to an innovation shock.

For architectural innovations in which the interactions and linkages among components are of central concern, incumbents are likely to differ in their adjustment costs. Knowledge sets of a firm can differ in both knowledge about components and the architectural knowledge about how these components interact. A new architectural innovation "destroys the usefulness of the architectural knowledge of established firms" (Henderson & Clark, 1990, p.9) because components interact with each other in new ways typically nonobvious to potential imitators. While an architectural innovation may destroy the usefulness of prior architectural knowledge, it nonetheless preserves the usefulness of the established firms' knowledge about the components. That said, firms are likely to differ in their range of knowledge, which may impact the absorptive capacity (Cohen & Leventhal, 1990) they possess. Absorptive capacity is a firm's ability to recognize the value of new, external information, assimilate it, and apply it to commercial ends, which supports its innovative capabilities (p. 128). Firms with little innovative capability in components before the shock are unlikely to possess much absorptive capacity to recognize the details of the architectural innovation and its interaction among components as well as possess the ability to quickly and easily develop a competing product. Those firms recently engaged in inventive and innovative activities are more likely to possess absorptive capacity than firms without such activities (Cohen & Leventhal, 1990). The existence of strong intellectual property rights further raises the cost and difficulty of coming up with a competing product as an imitator cannot purely copy the components and product without risk of litigation. Therefore, incumbents without absorptive capacity are likely to face high adjustment costs to understand interactions and linkages among components and imitate the innovation without violating intellectual property laws.

All else equal, the more that firms have recent invention and innovation activities in components the more absorptive capacity they are likely to possess, which may allow them to be more likely to recognize architectural innovations, absorb the key details of component interactions and linkages, and design and produce imitative competing products. For instance, Henderson and Cockburn (1994) in the pharmaceutical industry showed that firms that accumulated more component and architectural knowledge and competence through R&D were likely to show higher new inventive discovery productivity. Takeishi (2002) also confirmed in the automobile industry the positive relationships between the in-house retention of component and architectural knowledge on firm performance. In other words, the greater the absorptive capacity of a firm, the lower the adjustment costs for imitating the architectural innovation shock. Other factors, which we discuss and theorize about below, may influence the rate of imitation by incumbents. Nonetheless, as a baseline and holding all else equal, we predict that:

Hypothesis 1: Incumbents with comparatively higher absorptive capacity are more likely to imitate the innovation shock more quickly, all else equal.

In addition to absorptive capacity based adjustment costs, some firms may have strong incentives to incur substantial costs to accelerate imitation. In particular, in the early period of a new architectural innovation, opportunity costs for imitating slowly can be substantial if the innovator can quickly capture market share from an incumbent (Ferrier, Smith, & Grimm 1999; Henderson & Clark, 1990; Lee, Smith, Grimm, & Schomburg, 2000) undermining pre-existing economies of scale or scope. For instance, in an industry in which a subset of firms competes intensively with each other (i.e., highly overlapping products and customer segments), which sometimes is called an innovator's peer strategy group, an innovation shock can dramatically increase the likelihood of firm failure if an incumbent does not respond quickly and customers flock to the innovator or other imitators. In other words, the opportunity costs of not imitating quickly substantially exceed the opportunity costs of abandoning a firm's established position when customers flock to firms that locate in the new strategic position (Argyres et al., 2018). Other incumbents within the industry may be more distant competitors to the innovator because of product and customer segment differentiation and have such a strong market position that they therefore may suffer much smaller opportunity costs for delaying imitation. Indeed, such competitors even may face opportunity costs from imitating quickly by forgoing profits from a previously well-established position. Incumbents with high opportunity costs from adopting slowly compared to those incumbents who face high opportunity costs from imitating quickly are therefore more likely to act strategically to accelerate imitation even when their adjustment costs are high, lest they incur substantial opportunity costs that may jeopardize future profit streams and survival. We therefore predict:

Hypothesis 2a: Incumbents that compete intensively with the innovator are likely to imitate the innovation shock faster than incumbents that are differentiated, all else equal.

In the period immediately following a new architectural innovation, firms with high opportunity costs for imitating slowly have a strong incentive to take steps to accelerate imitation. One strategy to accelerate imitation is to adopt organizational arrangements like outsourcing even when such arrangements are not efficient over the long-run.[2] For instance, with the availability of a component factor market, which is common in the early period of architectural innovations (Holcomb & Hitt, 2007), firms can find and contract with suppliers quickly, play suppliers off one another to accelerate responsiveness, and provide high-powered incentives for rapid execution and delivery (Balakrishnan & Wernerfelt, 1986; Powell et al., 1996); although, outsourcing can make coordinating co-specialized investment difficult or give rise to ex post maladaptation including hold-up (Williamson, 1985). In contrast, while vertical integration can facilitate co-specialized investments and limit maladaptation and hold-up through fiat (Williamson, 1985), it also can be costlier, require more time to build desired assets and capabilities, and suffer from low-powered incentives and other sources of internal inertia and delay that accrues from various organizational failures (Zenger, Felin, & Bigelow, 2011). We therefore predict:

Hypothesis 2b: Incumbents imitating the innovation shock quickly are initially likely to outsource component production.

While accelerating imitation by outsourcing can mitigate opportunity cost concerns in the short-run immediately following the innovation shock, this strategic move, if unaltered, can harm a firm's economic position in the long-run. Architectural innovations imply that the underlying components are linked together into a coherent whole such that a modification to one component has profound consequences for the design and integration with other components (Henderson & Clark, 1990). Such tight coupling represents a type of co-specialization (Hoetker, 2005; Park & Ro, 2013; Wolter & Veloso, 2008). If co-specialization exists and the production of components is organized through

[2]Another approach for lowering adjustment costs not discussed in this paper is to acquire capabilities that are difficult to transfer across firm boundaries (Argote, Beckman, & Epple, 1990; Szulanski, 1996). Acquisition of newly-required knowledge lower adjustment costs (Rumelt, 1974; Teece et al., 1994). These strategies represent a variation of the make versus buy conundrum discussed above.

outsourcing, then the organizational structure over time can lead to mal-adaptation to disturbances that require coordination across components, inappropriate incentives to support needed co-specialization, underinvestment leading to low quality, and hold-up (Williamson, 1985, 1996; Zenger et al., 2011). Moreover, after firms imitate by adjusting after the shock and initial adjustment costs have been incurred diminishing their importance, competitive pressure can build in which transaction cost considerations will come to the fore. Firms whose components are not properly aligned with a transaction-cost economizing governance choice are likely to suffer performance consequences over the long-run, especially as the number of imitators grows and buyers becomes more price sensitive. The process by which early adopters switch from a buy to a make strategy is nontrivial (Argyres, Felin, Foss, & Zenger, 2012) and likely will be made only under competitive pressure to do so. We therefore predict:

Hypothesis 3: Incumbents that accelerate imitation are more likely to shift to in-house production as imitations and competition intensifies.

4 | U.S. SPORT BICYCLE GEAR-SHIFTING COMPONENT SET MARKET FROM 1985 TO 1995

The sport bicycle industry is comprised of nested subsystems (Murmann & Frenken, 2006; Simon, 1962) organized hierarchically (see Figure 1). With clear boundaries existing between sport bicycle segments (e.g., frame, handle bars, seats, rims, tires, gear-shifting components, etc.), innovations occurring in one segment historically did not change the design and assembly process for the rest of the bicycle (Murmann & Frenken, 2006) nor did it lead to changes in other segments. Most firms focused mainly on their own market segment (Galvin & Morkel, 2001). These facts allow us to explore the U.S. sport bicycle gear-shifting components market without need to address the other segments of the bicycle.

We study the U.S. sport bicycle gear-shifting components market from 1985 to 1995 as the empirical context within which to examine our hypotheses. The segment has existed for many decades and market participation was stable prior to as well as after the innovation shock window of index shifting. Indeed, only a few firms entered or exited during the decade after the innovation shock, each with negligible market shares, which makes the setting particularly attractive for

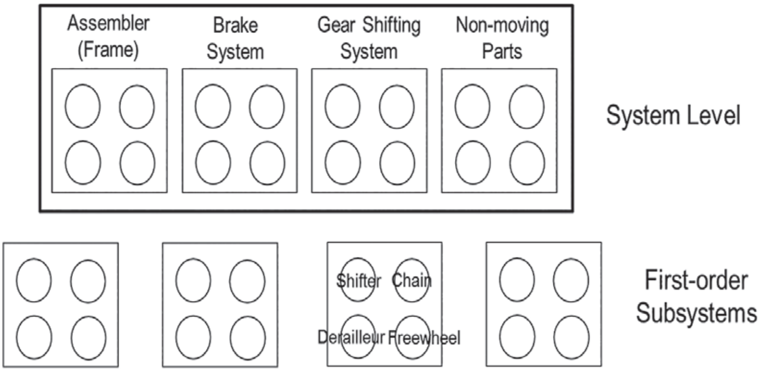

FIGURE 1 U.S. road bicycle segments from 1985 to 1995

FIGURE 2 Derailleur, freewheel, chain, and shifter

exploring firms' adoption timing and make-buy sourcing decisions without the empirical complexities of substantive entry and exit.

The set of gear-shifting components is comprised of a derailleur, a freewheel, a shifter, and a chain (Figure 2). The pre-shock derailleur was the key gear shifting component in 1985, and, perhaps because of this fact, 35 of the 43 firms in the market produced the derailleur in-house. Derailleur firms could source other components either internally (make) or though the market (buy) and offer a complete gear shifting set to bicycle original equipment manufacturers (OEMs). Prior to 1985, components and the linkages between them were modular and standardized (*Bicycling*, February/1986, pp. 38–41). Indeed, not only derailleur firms, but also bike riders enjoyed the benefits from mixing and matching these modular components (*Bicycling*, September/1981, pp. 72–71, 125; *Bicycling*, March/1982, pp. 92–108).

In 1985, Shimano Inc. (hereafter "Shimano") introduced index shifting, which can be identified as an architectural innovation shock because it redefined and reconfigured interactions among the gear shifting components. As a result, no longer could components be mixed and matched. Central to these design interactions was the *chain gap* (Fixson & Park, 2008), a concept and metric that did not exist for nonindex components sets. Creating an optimal chain gap is critical to performance: too narrow or too wide a chain gap led to missed shifting and increased sliding friction in pulling the chain onto the freewheel (*Bicycling*, January/February 1988, pp. 108–128). Chain design depended on chain gap, which also interacted with the design of the derailleur and freewheel (*Bicycling*, March/1987, p. 38). Additionally, high system performance demanded the shifter be specifically designed to fit a derailleur.[3] That index shifting made sport bicycle riding much more enjoyable and efficient for riders (i.e., shifting quickly to the correct gears with little friction made index shifting bicycles far superior to bicycles equipped with the prior technology) become known quickly. For instance, competitive bicyclists and indeed the entire component set industry knew quickly of the technical superiority of index shifting over prior technologies (see e.g., *Bicycling*, June/1985, pp. 39–41; Fine, 1998 [chap. 4, pp. 43–68]). This shifting advantage led to rapid adoption by enthusiasts and rapid growth in the market for index shifting. Figure 3a,b shows a clear growth trend of index shifting diffusion over the decade

[3]An additional ex post indicator that index shifting was an architectural innovation is that fact that Shimano's peer group immediately attempted to copy the innovation by retrofitting their existing components but that these imitations did not perform well. In essence, rivals realized they needed to design their own index system which led to firms like SunTour, Campagnolo, Sachs, and others introducing their own proprietary version of index shifting technology. Firms that competed directly with Shimano before the innovation shock also were the ones with the most to lose if they didn't imitate quickly because consumers adopted the innovation so quickly.

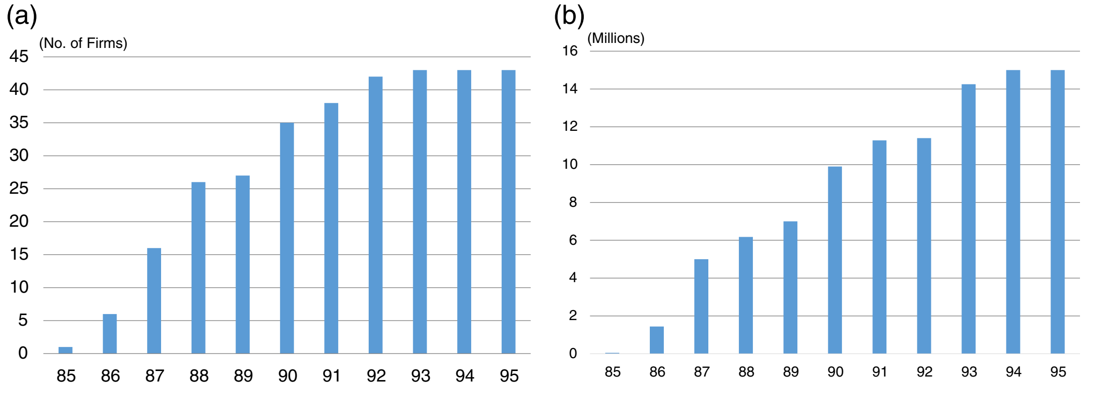

FIGURE 3 (a) Number of firms that adopted index shifting and (b) growth rate of index shifting (units sold)

with respect to the number of firms that imitated Shimano and offered index shifting systems and the number of system units purchased.

With 10 of the largest incumbent firms averaging an age of 60 years, all component manufacturers possessed deep knowledge of the industry. This knowledge may have kept firms from exiting the market. Conversely, market growth also stimulated little entry. Whether from entry barriers derived from the incumbents' deep market knowledge or the complexity of design and manufacturing, high performance index systems created entry barriers (Baldwin & Clark, 2000) as post innovation shock entry and exit was minimal over our window of study.[4]

The rapid rise in demand, the high complexity and novelty of designing the component set, and the rapid market impact of the index shifting innovation made imitation timing and sourcing decisions particularly strategic. Figure 3a shows that imitative entry took place over the entire decade indicating that firms differed in the timing of their strategic response to the shock; although, 80% of firms sold at least one index component set by 1990.

An important attribute of the firms with respect to our hypotheses is their heterogeneity in technical capacity. If we assume that bicycle patents prior to the shock offer a useful proxy in this market for absorptive capacity,[5] then firms differed substantially in their knowledge and ability to understand the interactions across the four critical components. For instance, Figure 4 displays substantial heterogeneity in firms' pre-shock patent portfolio; only a few firms had many patents. Firms also differed in their portfolio of patents with respect to the four gear shifting components.

Another important aspect of heterogeneity in this market is the fact that firms differed in their initial organizational decision for each component and that this decision varied over time Figure 5a,b illustrates that while some firms initially vertically integrated the chain, freewheel, and shifter, many more initially outsourced these components only to later shift sourcing to vertical integration. Late adopters more likely vertically integrated than outsourced and did not later change sourcing. These organizational decisions and later reversal for some of them are a critical phenomenon our theory attempts to explain.

[4]While little entry and exit occurred in the 10 years following Shimano's introduction of index shifting, the market experienced a stunning shakeout thereafter. In much like the market shakeout that occurred more than a decade after Ford introduced the Model T, 88% of firms exited the marketplace within 15 years of Shimano's index innovation. Therefore, whereas the lack of post-innovation entry might suggest that the market is somewhat unique, the eventual and resulting shakeout, which is a common dynamic found in many markets (Hannan & Freeman, 1984), suggests that this context may be generalizable.

[5]We explain in our section on Measures why patent count is an appropriate proxy for absorptive capacity in this context.

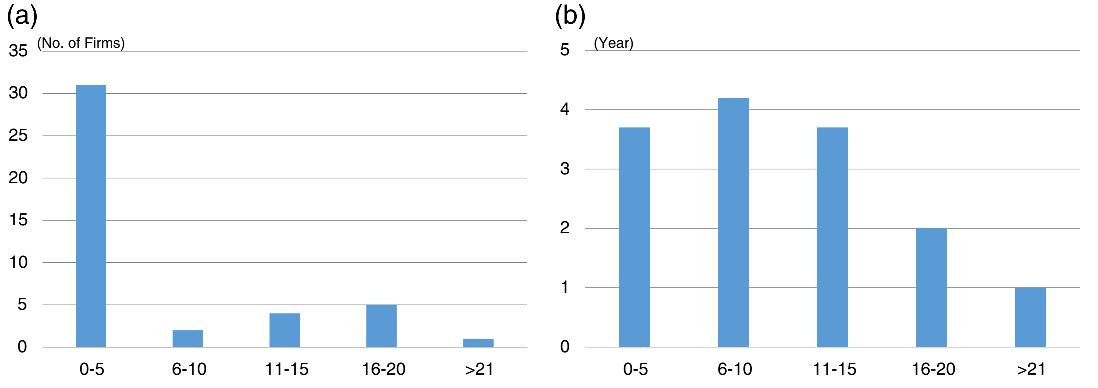

FIGURE 4 (a) Distribution of firms across patents and (b) number of patents and adoption timing

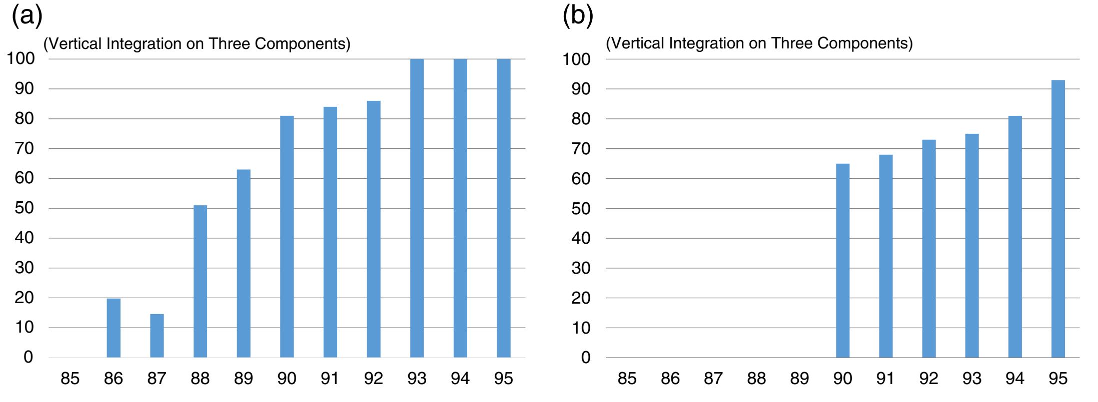

FIGURE 5 (a) Vertical integration evolution of early imitators (firms initially adopting index innovation 1985–1989) and (b) vertical integration of late imitators (firms adopting index innovation after 1989)

5 | DATA COLLECTION

We initially gathered data by observing individual gear-shifting components sets for each new bicycle model over $200. This approach provided comprehensive information about components and the make-buy sourcing decision by derailleur firms for each new gear shifting model in the sport bicycle market. Overall, the dataset included 43 derailleur firms that supplied gear-shifting component sets and 150 (individual component) suppliers with 1,859 distinct new component sets launched from 1985 to 1995.

During the timeframe of this study, associated trade publications provide primary knowledge and information sources within the bicycle industry. Bicycling aficionados and technicians alike consulted these publications, which made them a focal point for the market. *Bicycling*, one of the industry's leading trade magazines, generously provided its own proprietary database called Super Spec. The Super Spec database including pricing, performance, shifting mechanisms, component compatibility, component assembly instructions, original component manufacturer, and the like. The database contains 43 derailleur firms, accounting for approximately 95% of all shipments in the market.[6]

[6]This study found 51 derailleur firms, but used 43 firms. The other eight firms were minor players and so small that much of their corresponding data was missing in the database.

To verify the data, we acquired an alternative database from another leading trade magazine, *Bicycle Guide*. Other archival sources such as the *Proceedings of the International Cycling History Conference* and the book "*Dancing Chain*" also provided an understanding of both market and technological changes. In particular, *Sutherland's Handbook for Bicycle Mechanics (6th ed.)* contains over 700 pages with detailed figures and explanations of various bicycle components and their assembly. Often referred to as the "bible" among bicycle mechanics, the handbook contains details concerning components and their compatibility for all bicycle models from 1960 to 2005. The trade magazines *Bike Tech* and *Bicycle Guide* also contained a wealth of technological information. When combined, these various data sources give high confidence in data reliability.

6 | MEASURES AND ECONOMETRIC METHODOLOGY

Our measures include two dependent variables, three independent variables, and several control variables that other studies suggest are appropriate for our context.

$Adoption_{fst}$ is a binary dependent variable set to 0 for each year *t* and then set to 1 in the year (and all following months) in which firm *f* first introduces index shifting in a gear-shifting set *s*. *Adoption* empirically examines Hypotheses 1 and 2a.

$Sourcing_{fsct}$ is a binary dependent variable set to 1 if the derailleur firm *f* produced internally the component *c*—freewheel, chain, and shifter—for gear-shifting set *s* otherwise is set to 0. *Sourcing* empirically examines Hypotheses 2b and 3.

AC_Absorptive $Capacity_{fc}$, our measure of adjustment costs (AC), is measured as the number of patents[7] that firm *f* held for the 5-year window preceding the make-buy sourcing decision for each component *c*, where *c* represents derailleur, freewheel, chain, and shifter. Patent count is based on data obtained from the United States Patent & Trademark Office (USPTO) and coded by a patent attorney reviewing every claim in each patent. Some patents held claims for multiple components in which case the patent was counted for each component *c*. We assume that higher patent counts in the area of a particular component correspond to higher levels of absorptive capacity.[8]

Opportunity Costs (OC) associated with imitating slowly are measured by three co-variates—*OC_Price*, *OC_MKS*, and *OC_Peer Group*. To measure opportunity costs from imitating slowly requires an assessment of the degree of rivalry across firms. Research on identifying such rivalry has demonstrated, for example, that the similarity between strategic action and market power among rivals increases the intensity of rivalry between them (Gimeno, 1999; Gimeno & Woo, 1996). We

[7]To clarify, all firms had a combination of patent types, which we categorized as either prior component patents or architectural knowledge patents. In our measure of absorptive capacity, we only use prior component patents. In results not reported here, but available from the authors, we empirically tested the impact of architectural knowledge patents and component knowledge patents on adoption timing. We found that while the coefficient for component knowledge was positive and significant, the coefficient for architectural knowledge was not. These estimates are consistent with the idea that acquiring more component knowledge directly impacts the adoption timing of a new architectural innovation whereas prior architectural knowledge does not. Thus we rely on the relevant subset of patents as our measure of *AC_Absorptive* $Capacity_{fc}$.

[8]Patent counts are a commonly used measure for absorptive capacity (Jaffe, 1986; Jaffe & Trajtenberg, 2002); although, previous studies have called into question its use as a proxy (e.g., Cockburn & Griliches, 1988). For instance, firms differ in their propensity to generate patent innovations, and patents also significantly differ in terms of their knowledge content. However, our research context focuses on a single segment, which is the gear-shifting segment in the sport bicycle market, which insures greater focus in terms of the knowledge a patent count represents. In addition, while many firms received patents in the 5 years prior to the window of our study, no firm appeared to have a high propensity for patenting compared to the rates of patenting after the innovation shock. A set of patents based on such a narrow product focus and one single innovation represents a collection of discrete, distinct units of knowledge (Ahuja & Katila, 2001; Katila & Ahuja, 2002), which supports the notion of patent counts as an appropriate proxy for capturing absorptive capacity in our research setting (see also Song, Gnyawali, Srivastava, & Asgari, 2018).

use various measures of competitive intensity between Shimano and other firms to measure OC (Ferrier, Smith, & Grimm, 1999; Lee et al., 2000). We posit that incumbents in head-to-head competition with Shimano that did not quickly imitate index-shifting faced high opportunity costs as they would quickly lose market share, revenue, and profits. In contrast, other incumbents who were not in such head-to-head competition did not face such high opportunity costs from following slowly. Indeed, these incumbents may have suffered opportunity costs from moving too quickly and forgoing revenue from their established positions. In order to proxy for the degree of competition between Shimano and rivals we use three covariates.

OC_Price measures the number of months between Shimano's introduction of the *Aerodynamics* (AE) gear-shifting sets in 1981 and the date on which incumbents followed with a price increase. AE was Shimano's proprietary attempt to cosmetically streamline the design of gear-shifting set components to reduce air resistance. Given that most of the air resistance when riding a bicycle stems from the bike riders body, AE came to be regarded as a marketing ploy to charge a 15% price increase (*Bicycling*, April/1981, pp. 85–90). Such a price increase was unusual, especially when compared with the non-AE gear-shifting sets. Those incumbents who most closely competed with Shimano could use the price increase to follow with their own price increase thereby increasing profits and insuring that Shimano cold not increase profits disproportionally. Yet, incumbents more distantly located in product space were less likely to benefit from a Shimano price increase and would be less likely to imitate. We predict that the shorter *OC_Price*, the faster incumbents adopt the index shifting innovation (Hypothesis 1).

OC_MKS measures the market share difference between Shimano and an incumbent the year before index shifting was introduced to the market. The narrower the gap in *OC_MKS*, the more likely an incumbent was competing head-to-head with Shimano and the greater the opportunity cost from imitating slowly. We predict that incumbents adopt index shifting faster the smaller is *OC_MKS* (Hypothesis 1).

OC_Peer Group is set equal to 1 if an incumbent is among Shimano's peer group prior to the innovation shock, else 0 (low). *Bicycling* magazine, as well as other trade magazines such as *Bike Tech* and the industry writ large, identified 13 firms, Shimano among them, as a peer group competing intensely against each other. Firms identified in this group purportedly would have the greatest opportunity costs to responding slowly to index gearing. Moreover, opportunity costs from departing quickly from their established positions were minimal as the rapid adoption by customers of index shifting assured that prior positions were no longer economically sustainable even in the short run. For instance, Figure 6 shows that peer group firms imitated on average in 2 and a half years where nonpeer firms imitated on average in 5 and a half years. Figure 7 shows the product lines of each firm

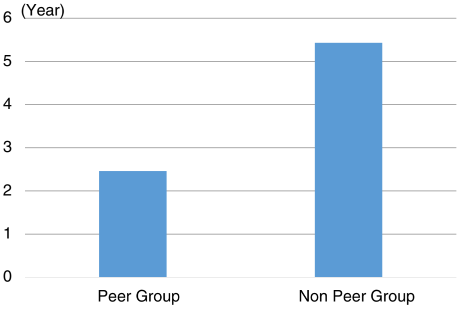

FIGURE 6 Peer group and adoption timings

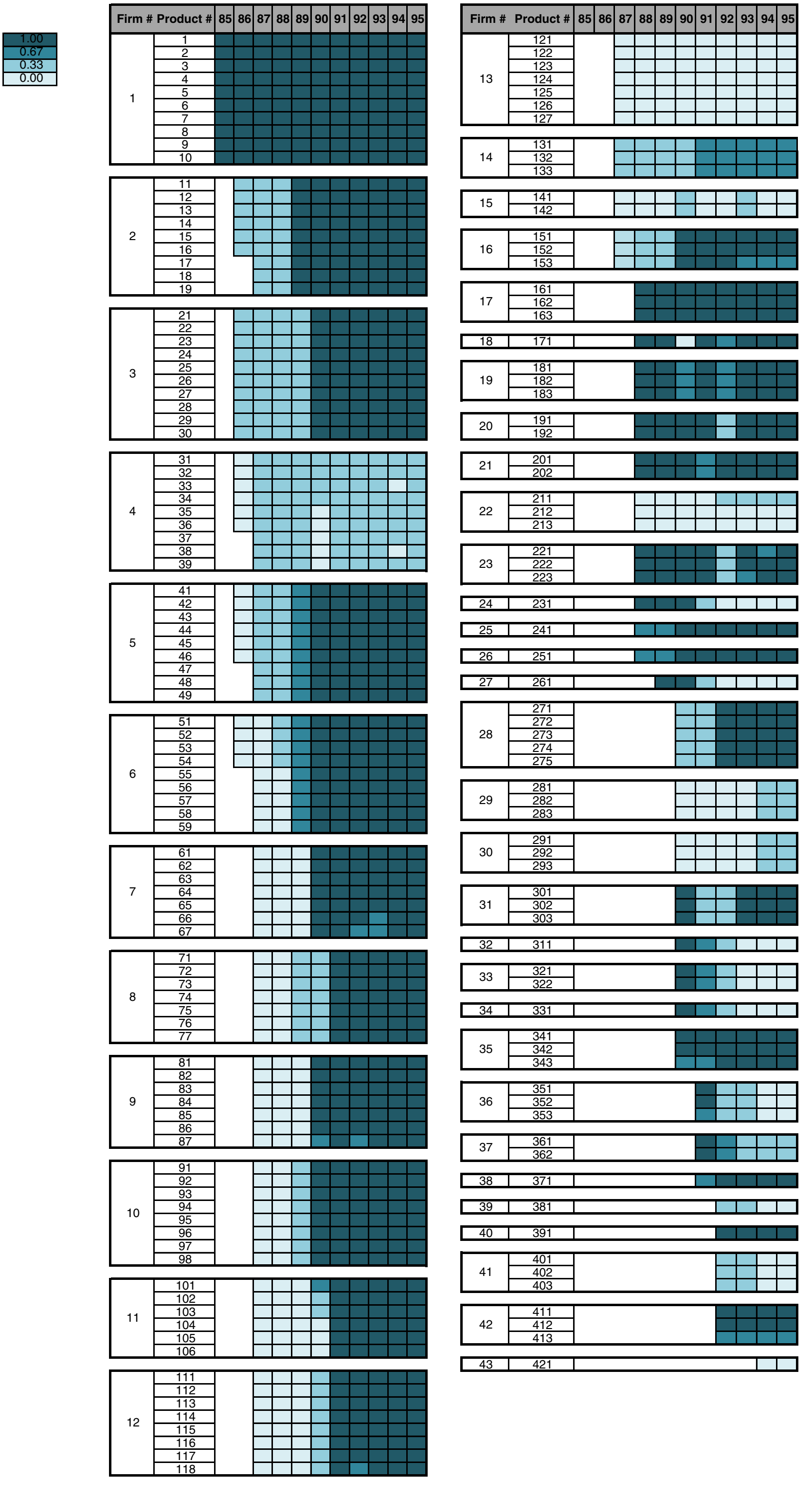

FIGURE 7 Vertical integration history

(total 43 firms). While firms #1–#13 in Figure 7 were in the peer group, firms #14–#43 were not in the peer group. Peer group firms average 6.7 different product lines per firm during the analysis period (1985–1995). These product lines were in head-to-head competition in the low, medium, and high price gear set segments. In contrast, firms in the nonpeer group on average had fewer product lines (average is 2.14 product lines), which signals they were focused on a narrow set of customers and market place needs. Incumbents outside of this peer group likely faced lower opportunity costs as they did not compete directly with Shimano (Ferrier et al., 1999; Lee et al., 2000). We thus predict that imitators in Shimano's peer group (*OC_Peer Group* equal to "1") are likely to quickly adopt the index shifting innovation (Hypothesis 1).

$Co\text{-}specialization_{fsct}$ is an independent variable that is, our proxy for transaction costs and coded 1 if a component c from firm f's gear shifting set s was co-specialized so that it could be used only with one set, else 0. Coding is based on two criteria (Hoetker, 2006; Hoetker, Swaminathan, & Mitchell, 2007). First, using *Bicycling*'s database we assessed more than 200 different offerings (c) across firms and product lines as to whether a component for a derailleur firm s was used for other derailleur firms. Second, we assessed component compatibility from *Sutherland's Handbook for Bicycle Mechanics (6th ed.).* We assume co-specialization if either a component is not used by other firms or if the component is not compatible with other index systems.

$P(Y_{fst} = 1)$ and $P(X_{fst} = 1$ and $Y_{fst} = 1)$ are needed to empirically evaluate Hypotheses 2b and 3, respectively, by constructing time-variant covariates.[9] Y_{fst} indicates whether a firm f adopted index shifting innovation in a given gear-shifting set s at time t during the early period (1985–1989): "1" indicates adoption, and "0" otherwise. We use the predicted value of Y_{fst}, which is $P(Y_{fst} = 1)$, for Hypothesis 2b in our sourcing decision regression model, Equation ((2). X_{fst} indicates whether a firm f adopted index shifting with a buy strategy for gear-shifting set s at time t during the early period (1985–1989). If the firm adopted with a buy strategy, X goes to "1." Otherwise, it is "0." We thus use $P(X_{fst} = 1$ and $Y_{fst} = 1)$ for Hypothesis 3 in our sourcing decision regression model Equation (2).

$Sourcing\ Duration_{fsct}$ is a control variable for the duration (in years) that a firm f has employed its current make or buy sourcing option for set s and component c, to account for the possibility that duration of a vendor relationship influence firms' future make-buy sourcing decisions (Gulati, 1995; Hoetker, 2006).

$Firm\ Size_{ft}$ is a proxy reflecting a firm f's market share measured as the proportion of units sold in year t in the entire bicycle market including road and mountain bicycles. Research in population ecology argues that larger firms are more rigid with bureaucratic organizational structures and incentive systems (Hannan & Freeman, 1984), which raises their adjustment costs (Argyres et al., 2015).

$Firm\ Age_{ft}$ is a control variable reflecting the length of time (in years) that firm f has produced gear-shifting sets. Firm age is commonly used, along with firm size, as a proxy for structural inertia (Hannan & Freeman, 1984). Older firms are less likely to make strategic changes (Argyres et al., 2015).

$Product\ Differentiation_{fct}$ is a categorical measure (0, 1, 2) that accounts for each firm f's pricing for each index set c, which indicates the price segment in which the component set competes. Even in a market with high product modularization, firms that differentiate may still pursue a make strategy instead of a buy strategy (Argyres & Bigelow, 2010) because differentiation requires them to incorporate unique components with fewer modular interfaces. Thus, product differentiation can affect firms' make-buy decisions. *Bicycling* magazine provided three segmentations by price (0, 1, and 2 level; the higher number indicates a higher priced category).

[9]We explain how to estimate $P(Y_{fst} = 1)$ as well as $P(X_{fst} = 1$ and $Y_{fst} = 1)$ for Hypotheses 2b and 3 in our Methods section.

Number of Suppliers$_{ct}$ is a control variable identifying the number of nonderailleur suppliers of component *c* in year *t*. Prior research indicates that the availability of suppliers can increase the likelihood of buying in the market instead of making internally (Williamson, 1985).

Finally, *Market Growth Rate$_t$* is a control variable that calculated the growth rate of the index shifting units sold at time *t*, compared with $t - 1$. As the demand for the index shifting innovation increases, firms will be more likely to adopt the innovation in order to satisfy the demand.

Descriptive statistics and correlations for all variables are found in Table 1a,b. We calculate correlations into two time periods: 5 years immediately following the innovation shock (early period) and years 6 through 10 (late period). Correlations indicate three areas of concern that affect our modeling choice. First, correlations among *the Absorptive Capacity* for *Freewheel*, *Chain*, and *Shifter* are greater than 0.9. Second, the correlation between co-specialization in the freewheel and shifter is perfectly correlated in the early period (1985–1989). Third, two correlations with respect to the number of suppliers of components—between chain and freewheel suppliers and shifter suppliers and *Market Growth Rate*—are high. Fortunately, assuming that we estimate sourcing decision coefficients separately for freewheel, chain, shifter, we can obtain variable inflation factors (VIFs) for each component equation. VIFs, which provide statistical tests for multicollinearity, reveal all values are lower than 10 and mean VIF was not distant from 1 for each component equation.[10] Thus, collinearity is not a concern for our analysis. Additionally, as we described below, we can account for these high correlations in our choice of methods.

Setting aside methodological considerations, correlations are broadly in line with our theory. For instance, the correlation between *Adoption* and *Peer Group* is positive and larger in the early period compared to the late period, which is consistent with Hypotheses 1 and 2a. Correlations between *Sourcing$_c$* and *Absorptive Capacity$_c$* in the early period in general are higher than correlation between *Sourcing$_c$* and *Co-specialization$_c$*. In contrast, in the late period the reverse is true: the correlations between *Sourcing$_c$* and *Co-specialization$_c$* in general are higher than the correlations between *Sourcing$_c$* and *Absorptive Capacity$_c$*. This pattern of correlations indicates that while firms may be more sensitive about their R&D capability than co-specialization in sourcing decisions in the early period, firm sensitivity reversed in the later period.

Moving beyond simple correlations, we empirically explore Hypotheses 1 and 2a by estimating the likelihood of adopting a new index shifting architectural innovation. Adopting the firm as the unit of analysis, we observe the adoption date on each gear shifting set by each firm. With multiple observations for each firm and therefore the need to consider firm level effects (Hoetker et al., 2007), we adopt a shared frailty model methodology with which to estimate a hazard rate (Gutierrez, 2002). A frailty model is the survival analysis analog to a (random-effects) Cox model for panel data that accounts for firm heterogeneity and firm-level random effects. The model assumes that each firm may have a systemically higher or lower rate of adopting a new innovation for reasons that the covariates cannot explain (Gutierrez, 2002). Equation ((1) highlights this difference by the term α_i, a random positive quantity assumed to have a mean of 1 (for purpose of model identification) and variance θ, which is orthogonal to the observed covariates. If the variance of unobserved heterogeneity parameter θ in Equation ((1) is not significantly different from 0 in our models, then we can conclude that unobserved heterogeneity among firms did not affect a firm's adoption of the new innovation.

$$h_{fs}(t) = h_0(t)\,\alpha f\ exp\left(x_{fs}\right) + \varepsilon, \tag{1}$$

[10]Results are available upon request.

TABLE 1 Summary of correlation statistics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(a) Early period: 1985–1989																									
1. Adoption	1.00																								
2. Sourcing_Freewheel	0.50	1.00																							
3. Sourcing_Chain	0.48	0.66	1.00																						
4. Sourcing_Shifter	0.54	0.54	0.48	1.00																					
5. Co-special._Freewheel	0.62	0.39	0.34	0.43	1.00																				
6. Co-special._Chain	0.35	0.48	0.45	0.52	0.56	1.00																			
7. Co-special._Shifter	0.62	0.39	0.34	0.43	1.00	0.56	1.00																		
8. AC_Absop.Cap._Freewheel	0.35	0.59	0.53	0.51	0.38	0.62	0.38	1.00																	
9. AC_Absop. Cap._Chain	0.34	0.57	0.52	0.48	0.40	0.62	0.40	0.98	1.00																
10. AC_Absop. Cap._Shifter	0.36	0.56	0.48	0.51	0.38	0.62	0.38	0.93	0.94	1.00															
11. OC_Price	−0.53	0.05	−0.01	0.05	−0.36	−0.38	−0.36	−0.27	−0.31	−0.25	1.00														
12. OC_MKS	−0.32	−0.11	0.09	0.01	0.07	−0.05	0.07	−0.04	−0.01	−0.04	0.01	1.00													
13. OC_Peer group	0.37	0.47	0.37	0.45	0.33	0.46	0.33	0.60	0.54	0.61	−0.38	−0.28	1.00												
14. $P(Y_{fst} = 1)$	0.57	0.41	0.29	0.44	0.44	0.39	0.44	0.51	0.49	0.51	−0.78	−0.42	0.73	1.00											
15. $P(X_{fst} = 1, Y_{fst} = 1)$	−0.00	−0.29	−0.37	−0.25	−0.16	−0.55	−0.16	−0.53	−0.52	−0.50	−0.06	−0.00	0.03	0.10	1.00										
16. Sourcing Dur._Freewheel	0.34	0.32	0.47	0.33	0.42	0.35	0.42	0.37	0.41	0.35	−0.13	0.31	−0.06	0.20	−0.18	1.00									
17. Sourcing Dur._chain	0.51	0.36	0.40	0.34	0.32	0.38	0.32	0.40	0.37	0.46	−0.44	−0.28	0.46	0.47	−0.44	0.17	1.00								
18. Sourcing Dur._Shifter	0.21	0.01	−0.03	0.13	0.27	0.00	0.27	−0.06	−0.06	−0.05	0.01	0.17	−0.05	0.05	0.22	0.55	−0.15	1.00							
19. Firm size	0.10	0.34	0.33	0.27	0.26	0.42	0.26	0.68	0.69	0.59	−0.25	−0.07	0.21	0.33	−0.53	0.30	0.19	−0.13	1.00						
20. Firm age	0.17	0.03	−0.05	0.18	0.17	0.04	0.17	0.08	0.08	0.06	−0.24	−0.13	0.25	0.41	0.31	0.01	−0.21	0.27	0.04	1.00					
21. Product differentiation	−0.10	−0.18	−0.10	−0.08	−0.18	−0.07	−0.18	0.03	0.01	0.05	0.12	−0.07	−0.01	−0.22	−0.22	−0.16	0.05	−0.11	−0.06	−0.15	1.00				
22. No. of Supp_Freewheel	0.15	0.02	−0.04	0.02	0.04	−0.09	0.04	−0.01	0.00	0.00	0.04	−0.00	0.00	0.03	0.45	−0.02	−0.02	−0.02	−0.08	−0.00	0.06	1.00			
23. No. of Supp._Chain	0.26	0.08	0.03	0.09	0.12	−0.02	0.12	0.02	0.03	0.04	0.04	0.00	−0.00	0.04	0.42	0.08	0.07	0.08	−0.13	0.01	0.07	0.97	1.00		
24. No. of Supp._Shifter	0.54	0.22	0.26	0.29	0.29	0.19	0.29	0.08	0.07	0.11	0.01	0.00	−0.00	0.07	0.14	0.32	0.28	0.34	−0.21	0.03	0.07	0.52	0.69	1.00	
25. Market growth rate	−0.47	−0.19	−0.21	−0.24	−0.24	−0.14	−0.24	−0.06	−0.06	−0.09	−0.01	−0.00	−0.00	−0.06	−0.21	−0.26	−0.23	−0.27	0.20	−0.02	−0.09	−0.65	−0.78	−0.98	1.00
Mean	0.51	0.24	0.20	0.27	0.28	0.11	0.28	2.30	2.55	2.26	1.79	12.17	0.62	0.73	0.43	7.15	7.98	7.32	0.57	59.3	2.27	83.2	32.4	25.0	0.84
SD	0.50	0.42	0.40	0.44	0.45	0.31	0.45	5.19	6.11	4.77	1.42	4.67	0.49	0.19	0.18	3.38	3.86	3.18	1.58	34.4	0.91	8.80	3.78	4.94	0.75
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	28.0	35.0	31.0	4.10	15.9	1.00	1.00	0.88	16.0	16.0	16.0	8.40	1.00	3.00	95.0	37.0	32.0	0.20
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.31	0.00	1.00	1.00	1.00	0.01	130	0.00	72.0	27.0	17.0	−0.03

TABLE 1 (Continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(b) Late period: 1990–1995																									
1. Adoption	1.00																								
2. Sourcing_Freewheel	0.33	1.00																							
3. Sourcing_Chain	0.31	0.69	1.00																						
4. Sourcing_Shifter	0.28	0.65	0.75	1.00																					
5. Co-special._Freewheel	0.29	0.41	0.39	0.31	1.00																				
6. Co-special._Chain	0.20	0.34	0.30	0.24	0.69	1.00																			
7. Co-special._Shifter	0.17	0.28	0.20	0.28	0.31	0.31	1.00																		
8. AC_Absop.Cap._Freewheel	0.02	0.18	0.18	0.21	0.20	0.31	0.32	1.00																	
9. AC_Absop. Cap._Chain	−0.01	0.15	0.15	0.17	0.16	0.26	0.27	0.98	1.00																
10. AC_Absop cap._Shifter	−0.08	0.11	0.10	0.13	0.14	0.27	0.28	0.93	0.96	1.00															
11. OC_Price	−0.16	−0.43	−0.31	−0.39	−0.33	−0.24	−0.25	−0.30	−0.27	−0.27	1.00														
12. OC_MKS	−0.13	−0.32	−0.34	−0.33	−0.33	−0.40	−0.35	−0.21	−0.10	−0.03	0.31	1.00													
13. OC_Peer group	0.13	0.32	0.35	0.34	0.35	0.41	0.33	0.58	0.43	0.48	−0.27	−0.37	1.00												
14. $P(Y_{fst} = 1)$	0.25	0.39	0.47	0.37	0.52	0.47	0.29	0.46	0.39	0.38	−0.55	−0.52	0.67	1.00											
15. $P(X_{fst} = 1, Y_{fst} = 1)$	0.02	−0.32	−0.27	−0.26	−0.33	−0.62	−0.35	−0.44	−0.41	−0.43	0.33	0.42	−0.42	0.38	1.00										
16. Sourcing Dur._Freewheel	0.08	−0.03	−0.02	−0.06	0.18	−0.01	0.02	0.38	0.42	0.38	−0.04	0.30	−0.06	0.07	0.12	1.00									
17. Sourcing Dur._chain	0.14	0.35	0.27	0.27	0.35	0.32	0.46	0.36	0.31	0.37	−0.39	−0.28	0.44	0.38	−0.55	0.23	1.00								
18. Sourcing Dur._Shifter	0.03	−0.10	−0.11	−0.10	0.08	−0.22	−0.01	−0.06	−0.05	−0.08	0.07	0.17	−0.05	−0.07	0.44	0.59	−0.06	1.00							
19. Firm size	0.09	0.17	0.19	0.11	0.23	0.24	0.02	0.30	0.30	0.28	−0.09	−0.16	0.17	0.47	−0.45	0.03	0.16	−0.17	1.00						
20. Firm age	0.02	0.09	0.10	0.12	0.07	−0.03	0.01	0.06	0.06	0.01	−0.16	−0.13	0.25	0.25	0.08	0.02	−0.19	0.26	−0.11	1.00					
21. Product differentiation	−0.08	0.11	0.12	0.17	0.03	0.03	0.09	0.11	0.10	0.10	−0.13	−0.12	0.24	−0.00	−0.30	−0.15	−0.00	−0.11	0.10	0.11	1.00				
22. No. of Supp_Freewheel	0.15	0.10	−0.01	0.01	0.21	−0.04	0.15	0.07	0.04	0.01	0.00	0.00	0.00	0.03	0.27	0.46	0.40	0.48	−0.05	0.05	−0.18	1.00			
23. No. of Supp._Chain	0.20	0.13	0.02	0.06	0.26	0.04	0.17	0.08	0.04	0.01	0.00	−0.00	0.00	0.02	0.25	0.49	0.43	0.52	−0.10	0.05	−0.15	0.93	1.00		
24. No. of Supp._Shifter	0.21	0.14	0.05	0.11	0.22	0.17	0.17	0.06	0.03	0.01	0.00	−0.00	0.00	0.01	0.12	0.35	0.31	0.37	−0.12	0.04	−0.07	0.46	0.74	1.00	
25. Market growth rate	−0.00	0.03	0.00	0.01	−0.02	−0.02	0.01	0.02	0.02	0.04	0.00	0.00	0.00	−0.18	−0.03	0.10	0.09	0.10	−0.12	0.01	−0.02	0.07	0.13	0.03	1.00
Mean	0.98	0.81	0.80	0.76	0.79	0.64	0.65	4.74	4.52	4.01	1.51	12.2	0.62	0.79	0.15	12.7	13.5	12.8	1.51	64.9	2.36	72	28.8	26.5	0.03
SD	0.15	0.39	0.40	0.43	0.41	0.48	0.48	9.97	10.8	8.04	1.31	4.67	0.49	0.18	0.12	3.53	3.98	3.35	2.35	34.4	0.93	10.6	4.45	5.13	0.82
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	46.0	54.0	39.0	4.10	15.9	1.00	1.00	0.61	22.0	22.0	22.0	10.5	136	3.00	87.0	35.0	32.0	1.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.27	0.00	3.00	3.00	3.00	0.01	3.00	0.00	59.0	22.0	16.0	−1.00

where f is the firm-level frailty, s is the gear-shifting model in firm f, and where x_{fs} = independent and control variables listed above.

Hypotheses 2b and 3 are empirically assessed using a seemingly unrelated regression (SUR) model. The SUR model consists of several regression equations, each having its own dependent variable and potentially different sets of exogenous explanatory variables. In this study, we investigate firms' make-buy sourcing decisions regarding a "set" of three components—freewheel, chain, and shifter (assuming all firms produce internally their derailleur). While the equation for each component is a valid linear regression on its own, additional efficiency is gained in an SUR model if errors are correlated across the equations (Zellner, 1962). For example, an organizational decision for a freewheel may have implications for the organization of the most closely coupled components, the chain. If a firm chooses to produce a freewheel internally, then the firm may be more likely to choose the same strategy for the chain. Indeed, correlations among *Freewheel*, *Chain*, and *Shifter* in *Co-specialization*, *Absorptive Capacity*, *Sourcing Durations*, and *No. of Suppliers* are all high (Table 1a,b) suggesting the benefits of adopting an SUR model. To account for the potential of firm-level effects, the SUR model is estimated using a cluster option with respect to each firm:

$$\begin{aligned} \textit{Sourcing Decision}_{sfc(t+1)} &= \beta_0 + \beta_1{}^* \textit{ Absorptive Capacity}_{fsct} + \beta_2{}^* \textit{ Opportunity Costs}_{ft} \\ &+ \beta_3{}^* \, P\left(Y_{fst}=1\right) + \beta_3{}^* \, P\left(X_{fst}=1 \text{ and } Y_{fst}=1\right) + \beta_4{}^* \textit{ Control Variables}_{fsct} + \varepsilon_{fsct}, \end{aligned} \tag{2}$$

where s is a gear-shifting set in firm f, c indexes three components (freewheel, chain, shifter), and t is time.

Estimating Equation (2) first requires an estimate of $P(Y_{fst} = 1)$ and $P(X_{fst} = 1$ and $Y_{fst} = 1)$ for Hypotheses 2b and 3, respectively.[11] $P(Y_{fst} = 1)$ is a predicted probability estimating the likelihood that firm f adopted the index shifting innovation in a gear-shifting set s at time t during the early period (1985–1989) and is calculated as the predicted probability of treatment using the following Probit estimation:

$$Y_{fst} = a + b^* \, X_{fst} + u_f + e_{ft} \; \left(\text{where } u_j \text{ is error between firms}\right), \tag{3a}$$

$$P\left(Y_{fst}=1\right) = P\left(Y_{fst}>0\right) = P\left(e_{ft}>-a-b^* \, X_{ft} - u_f\right) = \phi \, \left(a + b^* \, X_{fst} + u_f\right), \tag{3b}$$

where ϕ; is the CDF of the normal distribution, which ranges from 0 to 1.

$P(X_{fst} = 1$ and $Y_{fst} = 1)$ empirically examines Hypothesis 3, which is a predicted probability estimating the likelihood that a firm f adopted the index-shifting innovation with a buy strategy ($X_{fst} = 1$) in a component c in a given gear-shifting set s at time t during the early period ($Y_{fst} = 1$). The variable is calculated as the predicted probability of treatment by using the conditional probability.

$$P\left(X_{fst}=1 \text{ and } Y_{fst}=1\right) = P\left(X_{fst}=1 \mid Y=1\right)^* \, P\left(Y_{fst}=1\right), \tag{4}$$

where $P(X_{fst} = 1 \mid Y = 1)$ is the probability that a firm f chooses a buy strategy in a component c in a given gear-shifting set s on the condition that the firm adopted the index shifting innovation in the early period. In obtaining the predicted value of $P(Y_{fst} = 1)$ and $P(X_{fst} = 1$ and $Y_{fst} = 1)$, we included *Market Growth Rate* as an instrumental variable, which provides the growth rate of the index shifting innovation at time t, compared with $t - 1$. As the growth rate of the index

[11]Often, a simultaneous-equation regression is considered as a modeling option. However, using simultaneous-equation regression is improper because the three dependent variables could potentially be endogenous (e.g., Novak & Eppinger, 2001). Also, adopting a simultaneous-equation regression can lead to heteroscedasticity and non-normal distributions for the error terms, leading to biased estimates (Zellner, 1962).

shifting innovation increases, firms will be more likely to adopt the innovation in order to survive in the market.[12]

7 | RESULTS

Models 1 through 5 in Table 2 report coefficient estimates for the imitation timing decision (Hypotheses 1 and 2a). Model 1 is a baseline model and includes only control variables. Model 2 adds our proxy for *AC_Absorptive Capacity* and Models 3 through 5 additionally include our proxies (covariates) for *Opportunity Costs.* With each additional variable both the F statistic and log-likelihood increase substantially, indicating that these variables enable the statistical model to better fit the data. Theta (Θ) for Model 1 is distant from "0" and significant (3.22 [0.99], $p = 0.00$), indicating that each firm may have a systemically higher or lower rate of adoption timing for reasons that the covariates cannot explain (Gutierrez, 2002). Including *AC_Absorptive Capacity* in Model 2, theta become less distant from "0" and less significant (0.21 [0.16], $p = 0.02$), and by additionally including all three covariates for *Opportunity Costs* in Model 5, theta is statistically no different from "0" (0.02 [0.08], $p = 0.37$). Therefore, omitted variable bias is unlikely to be problematic for Model 5.

Hypothesis 1 predicts that the coefficient for *AC_Absorptive Capacity* will be positive and significant, which is indeed the case in Model 2 (+0.18 [0.02], $p = 0.00$), Model 3 (+0.14 [0.02], $p = 0.00$), Model 4 (+0.12 [0.02], $p = 0.00$), and Model 5 (+0.07 [0.02], $p = 0.00$). Additionally, we estimated marginal effects[13] of *Absorptive Capacity* on adoption timing, which is −0.07 (dy/dx). In other words, increasing a firm's portfolio by one patent increases the likelihood that the firm imitates index shifting innovation earlier by 7%. With imitation averaging 3.64 years, a one patent increase speeds imitation by 0.25 year. These results indicate that those firms with higher absorptive capacity (i.e., more patents) on gear-shifting components and hence lower comparative adjustment costs correspond to faster imitation of index shifting suggesting that their adjustment costs were lower.

Hypothesis 2a predicts that in Models 3 through 5 the coefficient for *OC_Peer Group* for *Opportunity Costs* will be positive and significant, but the coefficients for *OC_Price* and *OC_MKS* for *Opportunity Costs* will be negative and significant. Model 3 yields a large and statistically significant coefficient for *OC_Peer Group* (+1.45 [0.47], $p = 0.00$), which is consistent with Hypothesis 2a. Adding *OC_Price* and *OC_MKS* in Models 4 and 5 led to negative and significant coefficients (−0.83 [0.22], $p = 0.00$ in Model 4 for *OC_Price* and −1.02 [0.22], $p = 0.00$ in Model 5 for *OC_Price*; −0.09 [0.03], $p = 0.00$ in Model 5 for *OC_MKS*). However, as we add *OC_Price* and *OC_MKS*, the coefficient for *OC_Peer Group* is no longer significant in Models 4 and 5. *OC_Price* and *OC_MKS* seem to be better in representing opportunity costs in the bicycle market. These estimates indicate that the sooner a follower's pricing increase occurs in response to Shimano's price increase in 1981, the faster the follower will adopt the index shifting innovation. Similarly, the narrower the market share difference between Shimano and a follower before the advent of index shifting, the faster the follower will adopt the index shifting innovation, supporting our Hypothesis 1.

[12]*Market Growth Rate* is not concluded in the estimation of Equation ((2) because we did not theorize a relationship between market growth and organizational choice, which is consistent with transaction cost economics logic (see, for example, David & Han, 2004; Williamson, 1985). Nonetheless, for robustness, we re-ran Equation ((2) with *Market Growth Rate* as a covariate and found it to be insignificant and did not impact the sign, magnitude, nor significance of our other variable estimates. Results are available upon request.

[13]Marginal effects in a Cox model are not straight forward as the calculation depends on the baseline hazard. We thus first estimate (regress) years that a firm spent in adopting index shifting innovation on the same independent and control variables. Based on the estimation, we obtained marginal effects.

TABLE 2 Estimation results for adoption timing (Hypotheses 1 and 2a)

	Year: 1985–1995 Model 1 Coeff. (*SD*) [*p*-val.]	Year: 1985–1995 Hypothesis 1 Model 2 Coeff. (*SD*) [*p*-val.]	Year: 1985–1995 Hypothesis 2a Model 3 Coeff. (*SD*) [*p*-val.]	Year: 1985–1995 Hypothesis 2a Model 4 Coeff. (*SD*) [*p*-val.]	Year: 1985–1995 Hypothesis 2a Model 5 Coeff. (*SD*) [*p*-val.]
Adjustment costs (*AC*)					
AC_Absorptive capacity	–	+0.18 (0.02) [0.00]	+0.14 (0.02) [0.00]	+0.12 (0.02) [0.00]	+0.07 (0.02) [0.00]
Opportunity cost (*OC*)					
OC_Peer group	–	–	+1.45 (0.47) [0.00]	+0.29 (0.51) [0.57]	−0.03 (0.47) [0.96]
OC_Price	–	–	–	- 0.83 (0.22) [0.00]	−1.02 (0.22) [0.00]
OC_MKS	–	–	–	–	−0.09 (0.03) [0.00]
Sourcing duration	+0.16 (0.10) [0.11]	−0.01 (0.04) [0.78]	+0.03 (0.04) [0.55]	+0.02 (0.04) [0.72]	+0.02 (0.04) [0.65]
Firmsize	+2.37 (4.93) [0.00]	+1.72 (1.49) [0.25]	+9.96 (1.31) [0.45]	+1.53 (1.40) [0.28]	+6.53 (1.34) [0.63]
Firmage	+0.01 (0.01) [0.38]	+0.01 (0.00) [0.11]	+0.00 (0.00) [0.30]	+0.01 (0.00) [0.13]	+0.00 (0.00) [0.17]
Product differentiation	+0.30 (0.37) [0.42]	+0.08 (0.11) [0.45]	+0.04 (0.09) [0.68]	+0.09 (0.10) [0.39]	+0.03 (0.09) [0.70]
No. of suppliers	−0.02 (0.02) [0.37]	+0.01 (0.01) [0.12]	+0.01 (0.01) [0.35]	−0.00 (0.01) [0.82]	−0.01 (0.01) [0.58]
Market growth rate	+7.16 (1.54) [0.00]	+3.63 (0.65) [0.00]	+2.38 (0.62) [0.00]	+2.40 (0.67) [0.00]	+1.34 (0.62) [0.03]
N	169	169	169	169	169
F statistic	32.41	81.87	91.56	82.42	100.17
Log-likelihood	−667.40	−647.26	−641.71	−634.68	−629.13
θ	+3.22 (1.00) [0.00]	+ 0.21 (0.16) [0.02]	+ 0.09 (0.10) [0.11]	+ 0.11 (0.10) [0.07]	+ 0.02 (0.08) [0.37]

We also estimated the marginal effects of *OC_Price* on adoption timing, which is −0.29 (*dy*/*dx*), indicating that if a firm is in Shimano's peer group, then the chance of the firm imitating the index shifting innovation earlier increases by 29%, which equates to accelerating imitation by 1.06 years compared to the average of 3.64 years. Similarly, we estimated the marginal effects of *OC_MKS* on adoption timing, which is +0.04 (*dy*/*dx*), indicating that if a firm is in Shimano's peer group the chance of the firm imitating the index shifting innovation earlier increases by 4%, which equates to accelerating imitation by 0.146 years compared to the average of 3.64 years.

Controls are insignificant except for two covariates. The coefficient for *Firm Size* is positive and statistically significant in the baseline Model 1 but drops to insignificance when the coefficient for *AC_Absorptive Capacity* is added to the statistical models. Hence, *Firm Size* is unrelated to adoption timing of index shifting in the complete model. The coefficient for *Market Growth Rate* is positive and significant in all five models indicating that faster growth rates create incentives for faster adoption.

Models 6–9 in Table 3 estimate coefficients for the make versus buy sourcing decision for individual components. Models 6 and 7 estimate models for the 1985–1989 time frame, which is comprised of 337 observations, and Models 8 and 9 estimate models for the 1990–1995 time frame, which is comprised of 908 observations. Both Models 6 and 8 are baseline models. Models 7 and 9 incorporate the predicted probability that a firm adopted index shifting and accounts for the self-selection of imitation.

Hypothesis 2b is explored by juxtaposing the coefficients for *Co-specialization* and *AC_Absorptive Capacity* in Models 6 and 7 compared to Models 8 and 9. The coefficients for *Co-specialization* in Model 6 for all three components are insignificant (+0.15 [0.30], $p = 0.61$ for freewheel; −0.22 [0.56], $p = 0.70$ for chain; −0.03 [0.44], $p = 0.95$ for shifter). Similarly, after accounting for the likelihood of imitation, coefficient estimates are insignificant in Model 7 (+0.45 [0.39], $p = 0.25$ for freewheel; +0.07 [0.58], $p = 0.91$ for chain; +0.17 [0.45], $p = 0.71$ for shifter). These estimates

TABLE 3 Estimation results for sourcing decision (Hypotheses 2b and 3)

	Year: 1985–1989 Model 6	Year: 1985–1989 Hypothesis 2b Model 7	Year: 1990–1995 Model 8	Year: 1990–1995 Hypothesis 3 Model 9
<Sourcing on Freewheel>	Coeff. (S.D.) [*p*-val.]	Coeff. (S.D.) [*p*-val.]	Coeff. (S.D.) [*p*-val.]	Coeff.(S.D.) [*p*-val.]
Co-specializaton_Freewheel	+0.09 (0.27) [0.73]	+0.21 (0.30) [0.47]	+0.90 (0.18) [0.00]	+1.50 (0.35) [0.00]
Absorptive Capacity_Freewheel	+0.23 (0.12) [0.05]	+0.44 (0.16) [0.01]	+0.05 (0.02) [0.01]	+0.12 (0.05) [0.02]
Hypothesis 2b: $P(Y_{fst} = 1)$	–	−5.90 (1.58) [0.00]	–	–
Hypothesis 3: $P(X_{fst} = 1, Y_{fst} = 1)$	–	–	–	+3.93 (1.98) [0.05]
Sourcing Duration_Freewheel	+0.02 (0.56) [0.68]	−0.01 (0.07) [0.92]	−0.07 (0.03) [0.01]	−0.03 (0.03) [0.40]
Firmsize	+1.22 (7.30) [0.09]	+5.19 (9.66) [0.59]	+5.48 (3.58) [0.13]	+1.03 (0.42) [0.02]
Firmage	−0.01 (0.01) [0.10]	−0.01 (0.01) [0.20]	+0.01 (0.00) [0.06]	+0.01 (0.00) [0.02]
Product differentiation	+0.57 (0.19) [0.00]	+0.84 (0.20) [0.00]	+0.20 (0.09) [0.03]	+0.36 (0.14) [0.01]
No. of Suppliers_Freewheel	−0.01 (0.02) [0.62]	−0.01 (0.02) [0.75]	+0.03 (0.01) [0.00]	+0.02 (0.01) [0.01]
Constant	+1.86 (2.17) [0.39]	+6.62 (2.78) [0.02]	−2.38 (0.60) [0.00]	−4.11 (1.03) [0.00]
<Sourcing on Chain>				
Co-specializaton_Chain	−0.16 (0.47) [0.74]	+0.04 (0.56) [0.95]	+0.43 (0.14) [0.00]	+1.07 (0.25) [0.00]
Absorptive Capacity_Chain	+0.14 (0.06) [0.02]	+0.37 (0.07) [0.00]	+0.02 (0.02) [0.29]	+0.03 (0.02) [0.16]
Hypothesis 2b: $P(Y_{fst} = 1)$	–	−9.97 (2.57) [0.00]	–	–
Hypothesis 3: $P(X_{fst} = 1, Y_{fst} = 1)$	–	–	–	+6.13 (1.67) [0.00]
Sourcing Duration_Chain	−0.02 (0.07) [0.79]	+0.13 (0.11) [0.22]	+0.05 (0.02) [0.02]	+0.19 (0.04) [0.00]
Firmsize	−1.54 (1.67) [0.93]	−3.72 (1.43) [0.01]	+0.93 (0.29) [0.00]	+1.88 (0.48) [0.00]
Firmage	−0.02 (0.01) [0.04]	−0.02 (0.01) [0.19]	+0.01 (0.00) [0.04]	+0.01 (0.00) [0.00]
Product differentiation	+0.25 (0.17) [0.12]	+0.64 (0.21) [0.00]	+0.11 (0.09) [0.21]	+0.30 (0.10) [0.00]
No. of Suppliers_Chain	−0.08 (0.06) [0.16]	−0.07 (0.06) [0.24]	−0.02 (0.02) [0.23]	−0.13 (0.03) [0.00]
Constant	+3.98 (2.55) [0.12]	+10.1 (3.32) [0.00]	−0.21 (0.55) [0.75]	−1.11 (0.68) [0.10]
<Sourcing on Shifter>				
Co-specializaton_Shifter	−0.02 (0.34) [0.96]	+0.06 (0.36) [0.87]	+0.41 (0.15) [0.01]	+0.82 (0.23) [0.00]
Absorptive Capacity_Shifter	+0.22 (0.06) [0.00]	+0.28 (0.07) [0.00]	+0.03 (0.01) [0.08]	+0.07 (0.02) [0.00]
Hypothesis 2b: $P(Y_{fst} = 1)$	–	−4.32 (1.97) [0.00]	–	–
Hypothesis 3: $P(X_{fst} = 1, Y_{fst} = 1)$	–	–	–	+4.59 (1.74) [0.01]
Sourcing Duration_Shifter	+0.09 (0.06) [0.12]	+0.07 (0.06) [0.21]	−0.03 (0.02) [0.10]	+0.00 (0.03) [0.85]
Firmsize	+8.90 (1.45) [0.54]	+7.27 (1.39) [0.60]	+2.99 (3.35) [0.37]	+0.90 (0.48) [0.06]
Firmage	+0.01 (0.01) [0.20]	+0.01 (0.01) [0.12]	+0.01 (0.00) [0.11]	+0.01 (0.00) [0.01]
Product differentiation	+0.01 (0.17) [0.93]	+0.07 (0.18) [0.67]	+0.15 (0.08) [0.05]	+0.40 (0.12) [0.00]
No. of Suppliers__Shifter	+0.01 (0.06) [0.85]	+0.02 (0.07) [0.79]	+0.03 (0.01) [0.09]	+0.02 (0.02) [0.20]
Constant	−2.26 (2.12) [0.29]	−0.63 (2.79) [0.82]	−0.62 (0.47) [0.19]	−3.15 (1.15) [0.00]
N	437	437	1,014	1,014

imply that component co-specialization did not play a significant role in the sourcing decision for any component during the early period.

The coefficient estimates change substantially for sourcing decisions in the later period. The coefficients for *Co-specialization* in Model 8 are positive and significant (+0.73 [0.17], $p = 0.00$ for freewheel; +0.42 [0.14], $p = 0.00$ for chain; +0.31 [0.16], $p = 0.05$ for shifter). Accounting for outsourcing during the early period in Model 9 also leads to significant coefficients, albeit to varying degrees, for *Co-specialization* (+1.36 [0.26], $p = 0.00$ for freewheel; +0.94 [0.20], $p = 0.00$ for chain; +0.73 [0.23], $p = 0.00$ for shifter). These results indicate component co-specialization substantially influenced the decision to source components internally in the later period (1990–1995) whereas the prior results indicate that co-specialization did not affect sourcing in the early period. The coefficient estimates for *AC_Absorptive Capacity* also differ in important ways. In Model 6 (+0.09 [0.03], $p = 0.01$ for freewheel; +0.10 [0.04], $p = 0.01$ for chain; +0.17 [0.07], $p = 0.01$ for shifter) and Model 7 (+0.20 [0.07], $p = 0.01$ for freewheel; +0.21 [0.06], $p = 0.00$ for chain; +0.22 [0.07], $p = 0.00$ for shifter) coefficient estimates are all positive and significant. These results indicate that firms that held more patents were more likely to vertically integrate, but for producing the chain, indicating that they had lower adjustment costs.

Coefficient estimates for *AC_Absorptive Capacity* in Model 8 (+0.05 [0.19], $p = 0.01$ for freewheel; +0.02 [0.02], $p = 0.29$ for chain; +0.03 [0.02], $p = 0.08$) and Model 9 (+0.05 [0.02], $p = 0.03$ for freewheel; +0.06 [0.03], $p = 0.04$ for chain; +0.06 [0.05], $p = 0.25$ for shifter), however, tell a different story for the later period. These differences indicate that adjustment costs as measured by *AC_Absorptive Capacity* impacted sourcing decisions in the early period but had a less significant impact in the later period. Relatedly, Figure 4a indicates not many firms held a large number of patents when initially adopting index innovation.

One way to understand the impact of the coefficient estimates across Models 7 and 9 is to estimate the marginal effects on make versus buy for *Co-specialization* and *Absorptive Capacity*, which is plotted on an annual basis in Figure 8 for each component. For example, for the freewheel component in Figure 8, increasing a firm's patent count by one in 1987 corresponds to the probability of a make strategy increasing by 10%. In contrast, for the same year the probability of the firm choosing a make strategy for a co-specialized component would increase less than 2%. The characteristic

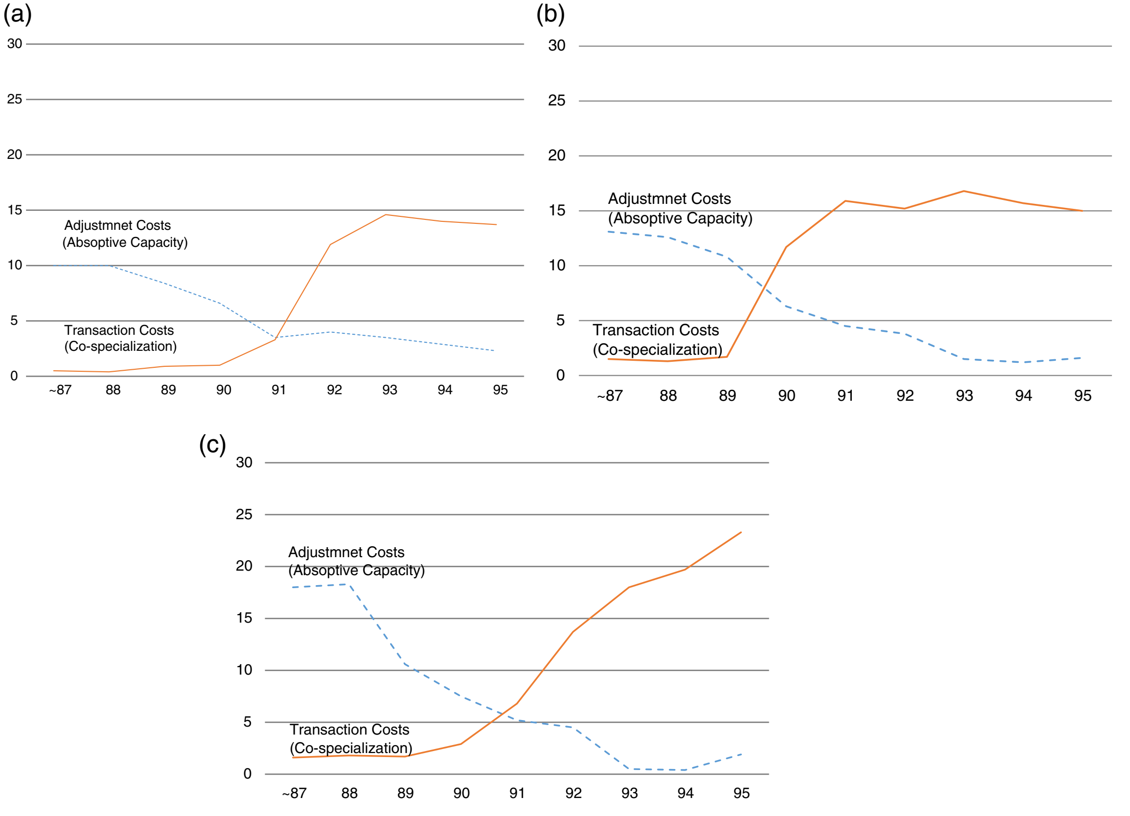

FIGURE 8 Marginal effect of co-specialization and absorptive capacity on sourcing decisions for each component

relationship is similar across all three components. Yet this relationship reversed around 1990 for all three components. For instance, the probability of a firm choosing a make strategy over a buy strategy in 1993 with an increase in one patent would increase less than 2%. Choosing a specifically designed freewheel in 1993 increased the probability of the firm choosing a make strategy by more than 15%.

Models 7 and 9 also provide coefficient estimates on covariates that accounted for self-selection. In Model 7 the coefficients for $P(Y_{fst} = 1)$ (−6.30 [1.53], $p = 0.00$ for freewheel; −6.89 [1.79], $p = 0.00$ for chain; −3.15 [1.07], $p = 0.00$ for shifter) indicate that those firms likely to enter in the early period were also very likely to outsource, which is indicated by the large and negative magnitudes of their coefficient estimates. For instance, the marginal effects of $P(Y_{fst} = 1)$ on each component are −0.32 for freewheel, −2.21 for chain, and −1.52 for shifter. These results indicate that if a firm adopted the index shifting innovation in the early period (1985–1989), then the chance that the firm initially utilizes an outsourcing strategy in freewheel, chain, and shifter will likely be higher than a firm that did not adopt the index shifting innovation in the early period by 32, 221, and 152% for freewheel, chain, and shifter, respectively, supporting Hypothesis 2b.

In Model 9, the coefficients for $P(X_{sft} = 1 \text{ and } Y_{fst} = 1)$ (+5.90 [2.02], $p = 0.00$ for freewheel; +9.59 [2.09], $p = 0.00$ for chain; +6.13 [2.09], $p = 0.01$ for shifter) indicate that those firms that entered the early period with a buy strategy were more likely to choose a make strategy in the later period. For instance, the marginal effects of $P(X_{sft} = 1 \text{ and } Y_{fst} = 1)$ on each component were +0.27 for the freewheel, +0.28 for the chain, and +0.54 for the shifter. These results indicate that if a firm adopted the index shifting innovation in the early period (1985–1989), then the chance that the firm internalizes a component in the later period (1990–1995) will likely be higher than a firm that adopted the index shifting innovation in the later period by 27, 28, and 54% for freewheel, chain, and shifter, respectively. Figure 5a,b provides additional support as early adopters, which on average started with an outsourcing strategy, tended to be faster in switching to a make strategy for the three components than late adopters. More specifically, in Figure 7, firms whose numbers are from 1 to 27 are ones that adopted index shifting between 1985 and 1989 (early adopters). Many of them started with a buy strategy and after 1990 they tended to switch to a make strategy in the later period, supporting Hypothesis 3.

The coefficient estimates for control variables across Models 6 through 9 vary in magnitude and significance and are not summarized in detail here. Nonetheless, taken together the set of coefficients provide an interesting insight. In particular, *Product Differentiation* covariates tend to increase the likelihood of vertical integration for freewheel, chains, and shifters in both the early and later. For instance, of the three coefficient estimates for these covariates in Model 7 only one coefficient (shifter: *Product Differentiation*) is not significant. And, in Model 9, all the coefficients of the variable are significant. One plausible explanation for this pattern of coefficient estimates is that in the high-end of the market, more specific and tightly coupled components were required to satisfy high-demanding bike riders thus firms were in greater need of the coordination benefits of vertical integration.

Taken together, the empirical evidence from Models 4 through 7 is consistent with Hypothesis 2b that incumbents in the early period strategically lowered adjustment costs to speed imitation by outsourcing even though doing so created transaction cost risks because of co-specialization. This empirical evidence also is consistent with Hypothesis 3: those firms that adopted organizational arrangements in the early period that were not transaction cost economizing reconfigured during the later period to adopt transaction cost economizing organizational arrangements. In short, co-specialization became more critical in the later period, to firms' make versus buy sourcing decisions than adjustment costs, which is consistent with prior research on the impact of misaligned governance after a shock (Nickerson & Silverman, 2003).

8 | DISCUSSION

Shimano's introduction of index shifting in 1985 launched an innovation shock that quickly began to shift demand to a new architectural product creating a powerful incentive for firms that produced sport bicycle gearing to quickly imitate the innovation. Yet, firms imitated this architectural innovation at different points in time—some quickly while others with substantial delay. Some firms adopted organizational configurations that did not accord with transaction cost economics and then later changed these organizational configurations while other firms adopted transaction cost economizing structures. To explain these variations in responses we built on a recently introduced theory by Argyres et al. (2018) and developed four hypotheses based on the context of the U.S. sport bicycle gear shifting market.

Our theory is based on the interaction of adjustment costs, transaction costs, and opportunity costs. In essence, those firms with low comparative adjustment costs were predicted to imitate quickly. Those firms with high comparative adjustments costs who also faced high opportunity costs by not adapting quickly—firms in Shimano's competitive set—were predicted to act strategically to accelerate imitation. We predicted that this strategic acceleration was achieved by outsourcing the production of freewheels, chains, and shifters even when co-specialization would argue for vertical integration thereby increasing long-run expected transaction costs. In essence, these firms traded off an increase in transaction costs for a decrease in adjustment costs because of high opportunity costs. We predicted that once repositioning took place, adjustment occurred, and opportunity costs diminished, competition would bring to the fore cost pressures that would encourage these early and inefficiently organized imitators to reconfigure the organization of transactions to economize on transaction costs. In contrast, those firms with high comparative adjustment costs and insufficient opportunity costs to justify strategically accelerating imitation were predicted to organize consistent with transaction cost predictions.

Our empirical results are consistent with our hypotheses. Models 1, 2, and 3 explored the imitation decision and found that the greater a firm's comparative absorptive capacity, our proxy for comparative adjustment costs, the sooner the firm imitates. Those firms in Shimano's competitive set, our proxy for high opportunity costs for imitating late, were much more likely to imitate quickly.

Our empirical analysis in Models 6 through 9 shows that in the early period co-specialization for all components did not statistically have an effect on the sourcing decisions but did have a significant and substantial effect in the later period. Relatedly, comparative adjustment costs for all components had a significant impact in the early period that encouraged outsourcing but this effect was insignificant in the later period. Accounting for the likelihood of imitating quickly shows fast imitators are much more likely to outsource components. Combined, these estimates are consistent with our predictions.

Our theory and empirical results add value to the economics, organization, and strategy literatures in at least four ways. First, this study is the first to theoretically and empirically explore the timing of imitation and the organizational choice for components based on theory that dynamically assesses the interplay between adjustment costs, transaction costs, and opportunity costs. Our findings support the general hypothesis that organizational leaders economize on the combination of comparative adjustment costs, transaction costs, and opportunity costs when making repositioning decisions in response to a shock, which leads to trade-offs especially in organizational structure that change dynamically as firms reposition. The paper also illustrates how specific predictions based on this general hypothesis must be developed with respect to the specific context; in our case, the sport bicycle gear train market. As such, our paper offers an initial response to recent calls to explain and empirically evaluate repositioning strategies in the face of an innovation shock (Argyres et al., 2015, 2018; Menon & Yao, 2017).

Second, the idea that firms willingly incur greater transaction costs to reduce adjustment costs is a bold proposition that provides an important caveat to Williamson's (1991) call that economy is the best strategy. Suggesting that noneconomizing organizational choices might confer a strategic benefit, albeit temporarily, is difficult to explain with conventional transaction cost logic. However, consideration of comparative adjustment costs and opportunity costs can lead to a conclusion that transaction cost misalignment can be an advantageous short-term strategy. Such a temporary strategy is one source of organizational vacillation (Nickerson & Zenger, 2002) as firms later are expected to find it in their best interest to reorganize to align transaction cost economizing principles as competitive intensity increases. For instance, early imitators in the sport bicycle market who outsource freewheel, chains, and shifters later vacillate from outsourcing to vertical integration.

Vacillation in response to shocks may be a phenomenon that is far more pervasive than the bicycle industry. For example, USA Today launched an online news room separate and independent from its traditional newspaper-based news room. This dual structure, while ambidextrous, led to bureaucratic infighting and high levels of governance costs, which arguably were not transaction cost economizing. Yet, by launching an online unit, USA Today was able to react quickly to an innovation shock of online distribution of mainstream news. Yet with an increase in competitive intensity and after USA Today successfully repositioned, vacillation occurred and the newspaper and on-line newsrooms were consolidated into a single—and some might say transaction cost economizing—structure (Boumgarden, Nickerson, & Zenger, 2012).

In addition, this dynamic interplay between adjustment costs and transaction costs represents a fruitful combination of insights from the literature on capabilities (Barney, 1991; Helfat & Peteraf, 2003; Penrose, 1959) and transaction cost economics (Williamson, 1985, 1996). Although some recent research demonstrates a connection between these two literatures, (e.g., Argyres & Zenger, 2012; Jacobides & Winter, 2005), our paper, following Argyres et al. (2018), provides an empirical test of how knowledge-based capabilities interact with transaction costs to dynamically effect governance decisions.

Third, the organizational literature often emphasizes organizational inertia, frequently proxied by firm age and size, as an important impediment to adaptation that also leads to survival advantages. While literature like population ecology emphasizes how inertia slows adaptation, this study offers a more nuanced perspective. Our theory and findings suggest that a recognition of high opportunity costs from departing early from an established position compared to repositioning late to a new position can provide the impetus to adopt strategies that overcome inertia, such as the outsourcing we describe above. Therefore, our analysis suggests that organizational leaders are actively and dynamically adopting strategies based on their comparative assessments of how to respond to shocks. Considerations of adjustment costs, transaction costs, and opportunity costs may shed new light on the interpretation of size and age effects in structural inertia theory (Dobrev et al., 2002; Hannan & Freeman, 1984) and the role of leaders in managing organizational responses to shocks.

Fourth, we believe that our paper offers practical insights for organizational leaders. Our analysis of firms in the sport bicycle gear shifting market is suggestive of the idea that organizational leaders can comparatively assess adjustment costs. In the context of sport bicycle gear sets, we explored publicly available information that yielded a proxy for adjustment costs that are pertinent for adapting to architectural innovation: patent counts. Such a comparative assessment (firms possess comparatively greater or fewer patents) could have provided managers an *ex ante* assessment of the ability of firms to imitate strategic moves. Similarly, managers could have qualitatively and comparatively assessed each firms' opportunity costs for departing their established position compared to the opportunity cost of arriving at a new position late. We assert that this information could have been used by managers—not just researchers—to help them assess strategic repositioning alternatives to an innovation shock, which provides at least one context in which the theories by Argyres et al. (2018) have currency.

We note that as with all empirical work, our study has limitations. We took advantage of the fact that our empirical setting was relatively stable prior to the innovation shock, comprised of relatively mature incumbents who possessed governance experience with both vertical integration and outsourcing. Both prior to and after the innovation shock there was little entry or exit. The relatively low levels of entry and exit make this an ideal setting in which to examine imitation at a granular level. But it also places limits on the degree of generalizability of our findings. Our theory and findings may derive from the sport bicycle gear shifting market components and therefore are not directly applicable to markets that are substantially different. Nonetheless, our empirical findings are supportive of not just our specific hypotheses but also of a more general theory that argues that organizational leaders dynamically choose repositioning strategies that economize on the conjunction of adjustment, opportunity, and transaction costs in response to a shock.

9 | CONCLUSION

We set out to better understand the puzzling variety of responses to an innovation shock among incumbent firms in the sport bicycle gear shifting market. Firms varied in when they imitated Shimano's architectural innovation of index shifting as well as varied in how they organized (i.e., through vertical integration or outsourcing) and how their choice of organization changed over time. Using recent theoretical developments on comparative adjustment costs (Argyres et al., 2015, 2018) and calls for empirical tests of strategic repositioning (Argyres et al., 2018; Menon & Yao, 2017), we posited that firms engage in trade-offs between comparative adjustment, transaction, and opportunity costs to determine strategic repositioning response when confronted with an innovation shock.

Using proxies that contain information accessible by organizational leaders ex ante, we empirically analyzed the timing of imitation, the organization of component manufacturing—namely the freewheel, chain, and shifter—and how the organizational choices change over time for early imitators as well as for late imitators. Econometric analysis yields coefficient estimates consistent with our hypotheses and the theory in general. These findings offer support for the view that, in response to a shock, organizational leaders dynamically choose repositioning strategies that economize on the conjunction of adjustment costs, transaction costs, and opportunity costs.

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