Complementary Assets as Pipes and Prisms: Innovation Incentives and Trajectory Choices

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Abstract

A long-standing interest in the technology strategy domain has been the failure of established enterprises in the face of radical technical change. In explaining incumbent failure, previous research focuses on incumbents’ under-investment in radical innovations. Despite this established perspective, however, it is commonly observed that incumbents make substantial investments in radical innovations, often at a magnitude no less than entrants. In order to address the paradox of incumbent failure despite heavy investments, we develop an analytical model that considers firm heterogeneity with respect to both technical trajectories and complementary capabilities. In this model, complementary assets play a dual role in incumbents’ investment behavior toward radical technological change: complementary assets are not only resources [pipes] that can buffer firms from technology change, but are also prisms through which they view those changes, in terms of both the magnitude of resources that should be invested and the trajectory to which these resources should be directed. When complementary assets are specific to a less promising technical trajectory, the incumbent is faced with a tradeoff between leveraging complementary assets and choosing a more promising technical trajectory. This analytical structure is used to provide insight into a number of empirical observations and offer new empirical implications.
1. Introduction

A long-standing interest in the technology strategy domain has been the question of the failure of incumbent firms in the face of radical technical change (Agarwal and Helfat 2009, Christensen 1997, Lavie 2006, McGahan 2004, Taylor and Helfat 2009, Tushman and Anderson 1986). In explaining such failure, early work within economics, such as Reinganum (1983) and Arrow (1962), stressed the incentives established firms face with respect to innovations that might replace their existing products or services. The strategy literature, such as Tushman and Anderson (1986), and work on evolutionary economics, such as Dosi (1982) and Nelson and Winter (1982), emphasized the distinct capabilities that alternative technology trajectories may require.

Both the economics and the strategy literature predict that incumbent firms fail because they under-invest in radical innovations. An innovation is radical in the economic sense if the new technology is a preferred substitute for the old technology (Arrow 1962, Reinganum 1983); for such innovations, the incumbent’s investment in innovation will cannibalize its existing products. Consequently, the incumbent’s marginal benefit of innovation is lower than that of the entrant and hence it will have less incentive to innovate than the entrant. An innovation is viewed as radical in the organizational sense if the innovation is competence-destroying with respect to a firm’s technical capabilities (Henderson 1993, Tushman and Anderson 1986). As a result of a competence-destroying innovation, the incumbent’s marginal cost for R&D investment is higher compared to the entrant equipped with the relevant technical capabilities. As a result, the incumbent will have less incentive to invest than an entrant with an appropriate capability set. Thus, while these two literatures take different perspectives, they share a common logic: incumbent firms fail because they under-invest in radical innovations. Further, such under-investment behavior can be justified on the basis of a rational calculation.

Contrary to these explanations, however, some in-depth case studies have shown that incumbent firms often failed despite their heavy investments in radical innovations (Rosenbloom 2000, Tripsas 1997, Tripsas and Gavetti 2000). Tripsas (1997) shows that a lack of investment in R&D was not responsible for incumbent failure in the typesetter industry that went through three generations of radical transformations. Incumbents actually invested large amounts in the new product generations: “qualitative data from interviews with both management and development engineers indicate that the level of investment by incumbents was at least equivalent to that of new entrants” (Tripsas 1997: 130). However, the technical performance of products developed by incumbents during each new technology period was inferior to the performance of the entrant’s products. Relatedly, Tripsas and Gavetti (2000) show that

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1 Germane to the current work, Dew, Goldfarb, and Sarasvathy (2006) extend the Arrow (1962) and Reinganum (1983) analysis to include the effect of complementary assets on an incumbent’s incentives in a patent race.

2 Another reason we might see the incumbent be less efficient is due to the adverse productivity effects of size in innovative activities (e.g., Elfenbein, Hamilton and Zenger 2010, Williamson 1975, 1985, Zenger 1994).
Polaroid committed substantial investments to digital imaging technologies when such technologies first emerged as a potential threat to its instant camera business: “An electronic imaging group was formed in 1981, and as part of this effort work began on a microelectronics laboratory. The microelectronics laboratory opened up in 1986 after a capital investment of about $30 million, and with an operating budget of about $10 million/year. By 1989, 42 percent of R&D dollars were devoted to exploring a broad range of digital imaging technologies (Tripsas and Gavetti 2000: 1152).” Despite such significant efforts, Polaroid declared bankruptcy in 2001. Rosenbloom (2000) shows that National Cash Register Company (NCR) was among the pioneers seeking to make a transition to electronics. NCR started engaging in in-house research activities in electronics as early as 1938 and entered the computer industry in 1953 by acquiring Computer Research Corporation (CRC), one of the first computer companies. While NCR eventually survived the technological change after decades of restructuring, it encountered a deep crisis in the early stages of this transition.

This gap between the theoretical literature and empirical observations is further illustrated by Kodak’s investment behavior vis-à-vis digital photography (Gavetti, Henderson and Giorgi 2004a, b). Digital photography appears to represent a radical technological change in both an economic and organizational sense. First, from an economic perspective, digital imaging can displace traditional film-based imaging. As Kodak entered the digital imaging field, it had to cannibalize its own traditional film sales. In contrast, the entrants from the computer and consumer electronics industries, such as HP and Sony, did not face the same problem. Thus, other things being equal, this cannibalization effect should have decreased Kodak’s incentive to invest in the digital imaging field.

Perhaps a more fundamental factor in determining Kodak’s investment behavior, however, is the shift away from the chemistry-based technology domain of silver-halide film to the electronic-based digital technology domain of digital cameras (Gavetti et al. 2004a, b). R&D initiatives along the new technology domain rendered obsolete the skills and knowledge that Kodak accumulated in the chemistry-based domain. In contrast, new entrants, including both new ventures and de alio entrants coming from electronic and computer industries, had a capability set consonant with the new technology domain. Thus, existing theories of both economic substitutes and competence-destroying change would predict that Kodak would lag behind in investing in digital photography.

However, in spite of these considerations, “Kodak had been investing heavily in digital imaging since the early 1980s, pioneering image-sensor technology in 1986 and entering the market with a variety of products during the 1990s” (Gavetti et al. 2004a: 1). By 1993, the company had already spent $5 billion, or 40% to 50% of its total R&D budget, on digital imaging R&D (Gavetti et al. 2004a, b). Despite these enormous efforts, Kodak has not achieved commercial and technical success in the digital camera market. While Kodak has been able to secure a significant share of the US digital camera market in unit
volume, Kodak lost $60 on every digital camera sold in 2001 and continued to post losses at least until 2003 (Gavetti et al. 2004a, b).

One explanation for the above paradox is agency behavior: Managers in incumbent firms, such as Kodak, squandered their retained earnings on new technologies in which they should not have invested since they did not have relevant capabilities for such new technologies. As a consequence, these incumbents spent an enormous amount of capital on such technologies but did not obtain an adequate return for their shareholders. From this perspective, such incumbent firms would have better served their shareholders by returning cash via dividends or share buybacks (Jensen 1993). We do not disagree with this possibility. In this study, however, we ask the following question: Can an incumbent’s investment, such as Kodak’s multi-billion dollar investment in digital imaging, be understood to be economically rational or should it be viewed as a misuse of its capital? In broader terms, what is the economic rationale for incumbents’ substantial investments in radical innovations that in many instances may yield only modest success? We develop an economic model to address this question. The model is admittedly simple, as the main purpose is to provide a transparent analytical structure for us to conceptualize and integrate various issues around this topic in the technology strategy literature. The remainder of the paper is organized as follows. Section 2 outlines our perspective in resolving the above puzzle. Section 3 sets up the model structure, and Section 4 provides the analysis. Finally, Section 5 offers some broader conclusions and implications.

2. A perspective on complementary assets and technical trajectories

Our explanation to the paradox characterized above centers around the impact of complementary assets on the incumbent firm’s investment behavior with respect to radical technological change. Teece’s (1986) work on the role of complementary capabilities brought to light the issue that the relevant capability set for firms is composed not only of technical capabilities, but also complementary capabilities in manufacturing and marketing. Subsequent to Teece (1986), Mitchell (1989) and Tripsas (1997) demonstrated the power of complementary capabilities in buffering established firms from the competitive forces wrought by changes in an industry’s technical basis. However, perhaps because the original motivation for considering complementary assets was the issue of an innovator’s ability to appropriate value from R&D investments conditional on a successful R&D outcome (Teece 1986), the previous literature on complementary assets has tended to focus on the effect of complementary assets on the ex-post performance of incumbent firms (Hill and Rathaemel 2003). We take this line of reasoning further and argue that complementary capabilities also importantly affect firms’ ex-ante level of R&D investment and its choice of technical trajectory. As characterized by Dosi (1982), a technical trajectory corresponds to a pattern of problem-solving and technical progress within a given technological
paradigm. For our purposes, we use the term to connote the particular class of technologies the firm is building upon and the nature of the technological performance attributes it is attempting to enhance.

In our analysis, we consider two forms of heterogeneity: heterogeneity with respect to technical trajectories and heterogeneity with respect to firms’ complementary capabilities. The prototypical setting one might imagine is an established firm with a substantial stock of complementary capabilities (ex., substantial downstream resources with regard to distribution and brand-name), but having its old technical basis negated by the emergence of a radical technological change and facing a decision as to which technical trajectory along which to invest: A trajectory that may have a lower inherent promise to be preferred by the market but allows the incumbent to leverage its existing complementary assets or a trajectory that has a higher inherent promise but would diminish the value of its complement assets. We term the former type as complement-preserving trajectory and the latter type as complement-disrupting trajectory. In contrast, potential entrants, lacking complementary capabilities, face no such tradeoff and will favor the complement-disrupting approach. Our analysis recognizes that the link between investments, trajectory choices, and market outcomes is mediated by the presence of complementary assets. What is central to this perspective is the heterogeneity along different dimensions of the firm’s capabilities and the interdependence among them (Helfat 1997, Mitchell 1989, Sosa 2009, Teece 1986, Tripsas 1997). Specifically, complementary assets can have the following dual role in affecting incumbents’ R&D investment.

On the one hand, complementary assets, if fungible, amplify returns on R&D investments for incumbent firms, thereby increasing incumbent firms’ economic incentive to invest in the new technical domain. Specifically, given the same R&D efforts, a larger stock of complementary assets allows a firm to appropriate a higher value (Teece 1986, Arora, Fosfuri and Gambardella 2001, Girotra, Terwiesch and Ulrich 2007). This implies a higher marginal benefit from R&D investment and thus a higher investment incentive. The empirical findings of Mitchell (1989) and King and Tucci (2002) that experience in prior sub-fields is positively associated with a firm’s likelihood of entering new, related sub-fields is consistent with this argument. Even more directly supportive of the above argument is Helfat’s (1997) work that indicates that firms are more likely to develop technologies that can utilize existing complementary technologies.

On the other hand, however, complementary assets may also bias incumbents’ choice of technical trajectories. Specifically, complementary assets can be trajectory specific in the sense that they are valuable in conjunction with a certain trajectory but lose significant value in conjunction with other ones. Therefore, incumbents endowed with complementary assets may have an incentive to choose a technical trajectory along which they can leverage their complementary assets, even if such a trajectory has a lower inherent promise to be preferred by the market.
Combining the above two perspectives, we provide a point of view in which complementary assets play a dual role in incumbents’ investment behavior toward radical technological change: Complementary assets are not only resources [pipes] that can buffer firms from technology change, but are also prisms through which they view those changes, in terms of both the magnitude of resources that should be invested and the trajectory to which these resources should be directed. When complementary assets are specific to a less promising technical trajectory, the incumbent is faced with a tradeoff between leveraging complementary assets and choosing a more promising technical trajectory.

To illustrate this tradeoff, reconsider the case of NCR noted earlier. After NCR acquired an early leader in the computer industry (CRC), NCR integrated CRC’s research activities in computer technology into the framework of NCR’s “overall product development program” in order to leverage NCR’s extensive sales forces, one type of complementary assets (Rosenbloom 2000: 1087). However, the choice of technical trajectory was also modified. “The binary arithmetic and limited input–output (I/O) capabilities of the 102-A [a general purpose computer] were well suited to scientific use, but appeared to the people in Dayton [where NCR’s headquarters is located] as obstacles to business application. As a senior engineer commented, ‘when you talked about a binary machine, you scared our salesmen’ (Rench 1984: 26).… Under pressure from Dayton, CRC designed the 102-D, using decimal arithmetic...(Rosenbloom 2000: 1089).”

Similarly, while Polaroid invested a significant amount in digital photography very early on, their digital efforts were “guided by a desire to eventually develop an instant digital camera/printer product termed ‘PIF’ for Printer In the Field…As the 1984 Annual Report’s Letter to shareholders stated, ‘We believe that there is considerable potential in developing new hybrid imaging systems that combine instant photography and electronics.’…Since the output was to be on instant film, [the PIF concept] leveraged the firm’s strong film-manufacturing capabilities. It was also, however, consistent with the firmly held belief in a razor/blade model (Tripsas and Gavetti, 2000: 1152).” Kodak followed a similar razor/blade model. Indeed, much of Kodak’s early investments in digital photography derived from its attempt to leverage complementary assets in the film business such as distribution channels and photo finishers. Kodak also developed hybrid products, such as the Photo CD, that allow customers to both store and view digital images from CDs on computer, which they can then print at home or in store (Benner 2010, Gavetti et al. 2004a).

Across these examples, it is clear that, while the probability with which the technical trajectory chosen by the incumbents is to be preferred by the market may be lower than that for alternative technical trajectories, this probability is not zero. Should this technical trajectory be preferred by the market, the incumbent is better able to fully leverage its existing complementary assets and gain greater market

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3 We draw the pipe/prism analogy from Podolny (2001).
success. Therefore, for a given range of complementary assets, it may be optimal for the incumbent to choose the less promising technical trajectory. Moreover, these complementary assets may provide an incentive for the incumbent to invest more than the entrant *ex ante*. *Ex post*, however, should the technical trajectory that is chosen by the incumbent prove not to be an effective way to engage the market, either as a result of the limits of technical progress along the performance dimensions pursued by the firm or the market’s valuation of those performance dimensions, the incumbent may have an inferior market outcome under certain conditions even with its higher investments. The incumbent firm is betting on the trajectory that yields, in expectation, the greatest profits; however, due to the impact of its existing stock of complementary capabilities, this is a different calculation than choosing the technical trajectory that is most likely to prove to be promising. As a consequence, it should not be uncommon to observe incumbent firms making what appear to be *ex-post* bad “bets.” We feel that the dual role of complementary assets can help explain situations like Kodak’s investment behavior and resulting market outcomes in digital photography. Kodak’s stock of relevant complementary assets in the imaging industry created strong economic incentives to invest in the new technical domain. However, in order to leverage its complementary assets, Kodak chose a technical trajectory that engages digital technology but in a manner that enables the firm to link this new technology to its existing assets and ways of competing (profiting from the development of images), despite possibly being aware that a more disruptive approach to digital photography might prevail.

Complementary capabilities are an asset to be leveraged, but at the same time bias a firm’s strategic choices. As a result of this dual effect, firms may rationally invest large sums in technology efforts that yield a relatively modest rate of technical advance. The incumbent may invest heavily but achieve a lower likelihood of technical leadership than similar investments yield for new enterprises established to pursue these new technological opportunities. It is thus important to recognize that the incumbent may choose different technical trajectories and therefore to distinguish between investment as an input or a behavior (dollars spent on R&D and acquiring new technologies) and the consequences or outcomes that stem from such investments (relative distance from the technology frontier, patented new technologies, successful products, and the like).

An important backdrop to these arguments is the question of the degree to which the market for complementary assets and technology are imperfect. To the degree that these markets do not function well, the entrant cannot get access to complementary assets (e.g., through contracting) and the incumbent may not gain access to external technology (e.g., through licensing). We assume that it takes time for the entrant to internally develop complementary capabilities since the adjustment costs of developing complementary assets in a short period of time are prohibitive (Dierickx and Cool 1989). Furthermore, following Teece’s original work (Teece 1986), we assume that the market for complementary assets is
imperfect, because such assets tend to be co-specialized or specialized to the firm and thus transaction costs are high. In the absence of these assumptions, the competitive supply of complementary assets would cause the asymmetry between the incumbent and the entrant to disappear or certainly dissipate.

Similarly, we assume that the markets for technology are imperfect (Arrow 1962, Nelson 1959) and hence do not consider the transaction activities for technology between the incumbent and entrant. The extent to which markets for technology are able to function depends on a number of factors, including the nature of knowledge and intellectual property rights and related institutions (Arora et al. 2001, Dushnitsky 2010, Dushnitsky and Lenox 2005, Dushnitsky and Shaver 2009, Elfenbein 2007, Goldfarb 2008, Ziedonis 2007). We discuss possible extensions that would include such issues in the discussion section.

In the next section, we formalize the above perspective with a simple model and in the following section characterize the basic patterns of behavior suggested by the model.

### 3. Model setup

We consider a stylized two-stage model to examine firms’ investment decisions with respect to a radical technological change. While radical in the sense of one generation of a product supplanting another, the investment may be made along different technical trajectories that either preserve or disrupt a firm’s existing complementary assets. We term the former type as complement-preserving trajectory and the latter type as complement-disrupting trajectory. In the first stage, an incumbent firm, denoted by \( I \), chooses to invest either along the complement-preserving trajectory or along the complement-disrupting trajectory. Let \( r \in \{0,1\} \) represent firm \( I \)'s chosen trajectory, where 1 represents the complement-disrupting technical trajectory and 0 represents the complement-preserving technical trajectory. We assume the market’s preferred trajectory, denoted by \( t \in \{0,1\} \), is uncertain. We further let the complement-disrupting trajectory be more promising, i.e., \( p = \text{Prob}(t = 1) > 0.5 \). As a result, the incumbent faces a tradeoff between choosing a less promising technical trajectory along which it can leverage its complementary assets and a more promising technical trajectory along which it cannot fully leverage its complementary assets. Given the entrant \( E \) is assumed to lack complementary assets and the value of \( p \) is postulated to be greater than 0.5, the entrant finds it in its interest to invest in the “complement-disrupting” trajectory. In this stage, we assume firm \( I \) plays as a Stackelberg leader who chooses its trajectory \( r \) and its R&D investment level \( u_i \) before firm \( E \) chooses its R&D investment level \( u_E \).

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4 To guarantee the existence of a unique equilibrium in a Stackelberg game, researchers usually assume that the follower would choose the action most favorable to the leader among the set of the follower's optimal actions (see, for example, footnote 17 in Moorthy (1988)). Furthermore, we also examined the case where the entrant is the Stackelberg leader and our main results hold. We have also examined the model under Nash equilibria in which the firms move simultaneously. We can derive similar results under a simultaneous-move setting; however, there exist
Firms’ technical trajectory, R&D investment, and the market’s preferred trajectory determine the “base utility” of firm $i$’s product, denoted by $U_i$. In particular, we assume the base utility for firm $E$’s product is $U_E = \delta^{1-t}u_E$, $0 < \delta < 1$. Namely, while its base utility increases in its R&D investment, it is discounted by $\delta$ if there is a mismatch between its trajectory (i.e., the complement-disrupting trajectory) and the realized market-preferred trajectory. Similarly, if firm $I$ chooses the complement-disrupting trajectory, we assume that $U_I = \delta^{1-t}u_I$. However, if firm $I$ chooses the complement-preserving trajectory, we assume that $U_I = \delta^t A^{1-t}u_I$, where $A > 1$ represents firm $I$’s complementary asset (the entrant’s complementary assets are normalized as one). Thus, the critical asymmetry between the incumbent and entrant is the incumbent’s possession of complementary assets along the complement-preserving trajectory. Specifically, firm $I$ is assumed to have some complementary asset that may increase its product’s base utility but such complementary asset is trajectory-specific – it will be leveraged only when the incumbent chooses the complement-preserving technical trajectory and when the market prefers the complement-preserving trajectory. We make this assumption regarding the limited fungibility of complementary assets to highlight the central tradeoff faced by the incumbent. In the subsequent analysis of the robustness of the model in Section 4.1, we allow complementary assets to have some degree of fungibility and retain some value in the complement-disrupting trajectory. Table 1 summarizes the two firms’ base utility functions under different scenarios.

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In the second stage, the two firms engage in quantity competition in the market. Let $q_i$ denote firm $i$’s product quantity. We consider a linear demand system where $p_i = U_i - \beta q_i - \gamma q_j$ with $\beta > \gamma > 0$ for $i \in \{I, E\}$ and $j \in \{I, E\}$, $j \neq i$. The above linear demand curve can be derived by considering a representative consumer with utility given by $U(q_1 + q_2) = U(q_1) + U(q_2) - \frac{1}{2}(\beta q_1^2 + 2\gamma q_1q_2 + \beta q_2^2)$ (Vives 2001: 145) and, as a result, the intercept $U_i$ in the linear demand curve can be interpreted as capturing the base utility of firm $i$’s product defined above. A similar demand relationship has also been used in Sutton (1997: 58-59) in modeling the impact of R&D investment on product quality.
Market competition equilibrium in the second stage

Given the firms’ technical trajectory and R&D investment level, we can specify their second-stage profit functions stemming from product market competition. We assume both firms have marginal production cost normalized to zero. Let $\Pi_i(U_I, U_E)$ denote the equilibrium second-stage profit of firm $i$ given $U_I$ and $U_E$. If $2\beta U_I - \gamma U_I > 0$ for both $i = I, E$, both firms choose positive production quantity, and the equilibrium production quantities and profits are given by $q_i = \frac{1}{4\beta^2 - \gamma^2} (2\beta U_I - \gamma U_I)$ and $\Pi_i(U_I, U_E) = \beta q_i^2$. If $2\beta U_I - \gamma U_I > 0$ holds only for one firm, for example, $i = I$, then only firm $I$ produces and we have $q_I = \frac{1}{2\beta} U_I$, $q_E = 0$, $\Pi_I(U_I, U_E) = \beta q_I^2$, and $\Pi_E(U_I, U_E) = 0$. This is similarly true for $i = E$.

R&D investment equilibrium and incumbent trajectory choice in the first stage

Following the literature (Rosen 1991, Sutton 1997), we assume that the cost of achieving $u_I$, $C(u_I)$, is sufficiently convex such that all profit functions are quasi-concave. A sufficient condition is that $\frac{C'(u_i)}{u_i}$ increases in $u_i$. Let $\Sigma^r_i(u_I, u_E)$ be firm $i$’s expected total profit given $u_I$ and $u_E$, if firm $I$ chooses trajectory $r$. Thus, we have

$$\Sigma^1_i(u_I, u_E) = p\Pi_i(u_I, u_E) + (1 - p)\Pi_i(\delta u_I, \delta u_E) - C(u_i)$$

$$\Sigma^0_i(u_I, u_E) = p\Pi_i(\delta u_I, u_E) + (1 - p)\Pi_i(u_I, \delta u_E) - C(u_i)$$

Conditional on firm $I$’s trajectory choice $r$, firm $i$’s R&D investment in equilibrium, denoted by $u_i^{*r}$, is given by $u_i^{*r} = \arg\max_{u_i} \Sigma^r_i(u_I, u_E(u_i))$, where $u_E(u_i) = \arg\max_{u_E} \Sigma^r_E(u_I, u_E)$, and $u_E^{*r} = u_E^{*r}(u_i^{*r})$. Let $\Sigma^{*r}_i = \Sigma^r_i(u_i^{*r}, u_E^{*r})$ be firm $i$’s equilibrium total profit given firm $I$’s trajectory choice $r$, and let $q_i^{*r}$ be firm $i$’s equilibrium production quantity given firm $I$’s trajectory choice $r$. Therefore, in equilibrium, firm $I$ chooses trajectory $r = 0$ over $r = 1$ if and only if $\Sigma_i^{0*} > \Sigma_i^{1*}$.

4. Analysis

We first characterize the effect of the incumbent’s complementary asset on the two firms’ investments and expected total profit in equilibrium.
Lemma 1: If firm I chooses the complement-disrupting trajectory, in equilibrium the two firms’ investment and expected total profit do not depend on A. If firm I chooses the complement-preserving trajectory, in equilibrium firm I’s (firm E’s) investment and expected profit increases (decreases) as A increases.

Proof: See Appendix.

Lemma 1 provides the key mechanisms regarding the economic incentives created by the incumbent’s complementary assets. When the incumbent chooses the complement-preserving trajectory, its expected profit will increase with the level of its complementary assets, as long as the likelihood that the market prefers the complement-preserving trajectory, however small, is greater than zero. The reason is that the existence of complementary assets increases the incumbent’s marginal return of R&D investment and hence encourages the incumbent to invest more in equilibrium. In contrast, the incumbent will not be able to leverage its complementary assets if it chooses the complement-disrupting trajectory. Therefore, as the level of the incumbent’s complementary assets increases, the incumbent is more likely to choose the complement-preserving trajectory. Lemma 1 also shows the negative impact of the incumbent’s complementary assets on the entrant. The entrant is discouraged to invest due to two effects. One is a direct effect, namely, the complementary asset increases the incumbent’s ability to appropriate from its innovative efforts and hence reduces the entrant’s marginal revenue. The other is an indirect effect caused by the increase of the incumbent’s investment.

Lemma 1 provides a rationale for the incumbent’s heavy investment in radical innovations. Next we address the central question that we posed in the Introduction: Why incumbent firms often failed in the face of radical technological change despite their heavy investments. To this purpose, we further compare the market outcome of the incumbent’s R&D investment vis-à-vis the entrant. In characterizing the market outcome, we examine how the two firms’ trajectories differ, which firm invests more, and which firm leads the market in terms of achieving larger market share. It is important to note that the comparison in terms of ex-post market outcome may be different than the comparison in terms of ex-ante investment. Specifically, when the two firms choose the same technical trajectory, the investment amount and market outcome have a one-to-one relationship. However, when firms are likely to take different technical trajectories, such a relationship does not hold. With heterogeneous technical trajectories, an equal investment in R&D may not lead to an equal market outcome. The following proposition shows that the market outcome can be characterized by three threshold values of the incumbent’s complementary assets.
**Proposition 1:** For any $0 \leq \delta \leq 1$, there exist three thresholds $A^r(\delta) \leq A^u(\delta) \leq A^l(\delta)$ such that i) if $1 < A < A^r(\delta)$, firm I chooses the complement-disrupting trajectory $r=1$ (i.e., $\Sigma^0_I < \Sigma^1_I$), ii) if $A^r(\delta) < A < A^l(\delta)$, firm I chooses the complement-preserving trajectory $r=0$ (i.e., $\Sigma^0_I > \Sigma^1_I$) and invests less than firm E, iii) if $A^l(\delta) < A < A^u(\delta)$, firm I chooses the complement-preserving trajectory $r=0$ (i.e., $\Sigma^0_I > \Sigma^1_I$), invests more than firm E, but does not lead the market (i.e., $q^0_I > q^0_E$) if the market prefers the complement-disrupting trajectory $t=1$, iv) if $A^l(\delta) < A$, firm I chooses the complement-preserving trajectory $r=0$, invests more than firm E and leads the market (i.e., $q^0_I > q^0_E$), even if the market prefers the complement-disrupting trajectory $t=1$.

Proof: See Appendix.

Proposition 1 shows that firm I’s trajectory choice and investments depend on both the level of complementary assets and the penalty from technical mismatch. A higher level of complementary assets encourages the incumbent to choose the complement-preserving trajectory, and encourages larger investment given its choice of the complement-preserving trajectory. Further, when we look at the choice of technical trajectory and investment level simultaneously, various interesting possibilities emerge. Specifically, by varying the degree of heterogeneity with regard to the stock of complementary assets and the penalty from technical mismatch, Proposition 1 characterizes distinct regimes with respect to choices of technological trajectory and product market outcomes. Figure 1 illustrates these regimes for the case where $p = 0.7$, $\beta = 1$, and $\gamma = 0.5$, where the vertical axis $A$ captures the incumbent’s higher complementary assets (recall the entrant’s complementary assets are normalized as one), while the horizontal axis $\delta$ captures the penalty from the mismatch between its chosen trajectory and the realized market-preferred trajectory. In all the numeric analyses, we use the cost function $C(u_I) = (\max(u_I - 1,0))^2$.\(^6\)

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\(^6\) This cost function is chosen solely for the ease of numeric study, as it satisfies the condition that $\frac{C(u_I)}{u_I}$ increases in $u_I$ and thereby guarantees that the profit function is well behaved. Further, we can understand the 1 in this functional form as a normalization of the minimum investment required to enter and provide a product that achieves some minimum “base utility” level. Numeric results are similar if we use a different normalization values such as 0.5.

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The dotted region in Figure 1 corresponds to a setting in which the incumbent chooses the complement-disrupting trajectory and competes on the same basis as the entrant. In some cases, the incumbent has a modest set of complementary assets and therefore these complementary assets do not
bias the incumbent away from the complement-disrupting technical trajectory. As a result, the incumbent is willing to give up its historical endowment and take on the complement-disrupting technical trajectory. The grey region corresponds to a setting in which the incumbent chooses the complement-preserving technical trajectory, invests less than the entrant, and experiences a lower market share if the market prefers the complement-disrupting technical trajectory. This setting is consistent with the empirical observations made by Tushman and Anderson (1986) that incumbents tend to invest less in competence-destroying innovations where they lack competence. At the same time, however, this setting offers an alternative explanation to this empirical observation: the incumbent’s lower competence with respect to the new innovation may be an outcome of their endogenous choice of how the firm chooses to respond to the technological opportunities that they face.

The white region depicts a setting in which the incumbent chooses the complement-preserving trajectory but still “wins” despite the fact that the market prefers the complement-disrupting trajectory. This setting represents a kind of “lock-in” region in which the market prefers the new technology but with not quite enough intensity ($\delta$) relative to the incumbent’s stock of complements ($A$). This finding is akin to work on standards (Arthur 1989, Shapiro and Varian 1999) in which it is shown that inferior technologies may come to dominate as a result of early market presence and the presence of strong network externalities.

If the incumbent has indeed amassed a sufficiently large stock of complementary assets, these complementary assets may create a sufficient incentive for the incumbent to invest significantly more than the entrant. In this case, even if the incumbent takes an inferior technical trajectory, the incumbent may still maintain a larger market share due to its large investment. Consider the engagement of newspaper firms in digital media as characterized by Kim (2010). Kim (2010) shows that firms such as the New York Times, which has a large set of complementary assets (e.g., content, journalist team, social status) are more inclined to develop websites that develop digital media in a manner similar to that of print media, while firms such as the Denver Post, lacking in such complementary assets, are more likely to develop websites that are more distinctive to the technology of digital media. Both the look and feel of the two websites and the degree of interactive components seem consistent with this argument. In contrast, a new entrant such as Slate or Yahoo adopted a pure digital form with little reference to traditional print news.

The black region in Figure 1 corresponds to the puzzle that we introduce in the beginning of the paper, where the incumbent chooses the complement-preserving trajectory, invests more, but achieves a

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7 In the figures, due to the choice of parameter values, the white region hits the ceiling of the figures when the penalty from technical mismatch $\delta$ is very small. In fact, the white region will exist even when the penalty from technical mismatch $\delta$ is close to zero.
lower market share than the entrant if the market prefers the complement-disrupting trajectory. The prior examples of Kodak, Polaroid, and NCR all correspond to this regime. Thus, we are suggesting that these firms, despite their unfavorable outcomes, may well have made rational investments that attempted to engage emerging technologies in ways that allowed them to leverage their existing complementary assets. Indeed, as Benner (2010) shows, stock analysts reacted quite favorably when Kodak invested in “hybrid” products.

Proposition 1 lays out the overall distribution of various possible regions; however, it does not yet specify the conditions under which each region will occur. In particular, Proposition 1 consists of a set of weak inequalities. The following Proposition characterizes when the distinct regions will, in fact, exist.

**Proposition 2:** For any $0 \leq \delta < 1$, there exists $0 < \tilde{p}(\delta) < 1$ such that $A^r(\delta) > 1$ when $p > \tilde{p}(\delta)$. Further, there exists $\bar{\delta} > 0$ such that for all $\delta \leq \bar{\delta}$, $A^u(\delta) < A^l(\delta)$.

**Proof:** See Appendix.

Proposition 2 states that the incumbent will choose the complement-disrupting trajectory only when the likelihood of the complement-disrupting trajectory being preferred by the market is sufficiently large. Otherwise, it may be possible that the incumbent always chooses the complement-preserving trajectory even when its complementary assets are the same as the entrant (i.e., $A^r(\delta) = 1$). More importantly, Proposition 2 states that, if the penalty of technical mismatch is high enough (i.e., $\delta$ is small enough), there is a region in which the incumbent chooses the complement-preserving trajectory, invests more than the entrant, but attains a smaller market share should the complement-disrupting trajectory be preferred by the market.

The black regime characterized by Proposition 1 and Proposition 2 helps explain why an incumbent can fail in the face of radical technological change despite its heavy investment. In our model, radical technological change is captured by the fact that, due to the emergence of a complement-disrupting technical trajectory, the entrant is not in a disadvantageous position vis-à-vis the incumbent in terms of technical capabilities; in that regard, the entrant can compete on the same basis as the incumbent. Furthermore, the incumbent has to choose between the complement-preserving and the complement-disrupting technical trajectory in pursuing the radical technological change. Should the incumbent choose the complement-preserving trajectory, it would have an incentive to invest more than the entrant due to the existence of complementary assets, which can amplify the return from a given level of investment. At the same time, however, the existence of complementary assets also makes it more attractive for the incumbent to choose the complement-preserving trajectory, as it can fully leverage complementary assets.
when the market prefers this trajectory. When the parameters are in the black region of Figure 1, the above two forces generate this distinct regime.

Propositions 1 and 2 characterize a kind of path dependency, but it differs from the standard notion of path dependency, which generally suggests some behavioral mechanism that reinforces the firm’s current pattern of action and investment. In our model, the incumbent is acting rationally and is forward looking. It is induced by its complementary assets to make its particular technical choice. The incumbent has the option to give up its complementary assets and take the complement-disrupting trajectory, but it is a rational decision for it not to do so. It is true that the complement-disrupting technical trajectory is more likely to be preferred by the market, but this is not certain. Therefore, a little bit of uncertainty and the inducement of complementary assets can generate the pattern that, \textit{ex post}, the incumbent seems to make a mistake. It invests heavily in its complement-preserving trajectory despite evidence to suggest that the complement-disrupting trajectory is more likely to be preferred by the market. Such behavior may appear to be irrational and perhaps reflect some pathology of organizational inertia. But, \textit{ex ante}, despite the likelihood that the complement-disrupting trajectory may be preferred, it still may be rational for the incumbent not to, effectively, throw away their complementary assets and become equivalent to the entrant. It is certainly possible that a firm may irrationally ignore the possible benefits of leveraging new technologies, but it is important to recognize that incumbents, in the face of radical technological change, may be sensibly maximizing their \textit{ex-ante} expected returns and not failing to realize the full strategic implications of their decisions.

We next examine the impact of complementary assets on market outcomes when the market prefers the complement-disrupting trajectory. This analysis offers testable implications and highlights the mechanisms that lead to such implications. Specifically, we use market share to measure the product market outcome.

\textit{Proposition 3: There exists }0 < \delta < 1 \text{ such that when } 0 < \delta < \delta_p, p > p(\delta), \text{ and the complement-disrupting trajectory is preferred by the market, firm I’s market share is non-monotonic as } A \text{ increases from 1 to arbitrarily high levels. In particular, firm I’s market share is constant with respect to its level of complementary assets when } A < A^*(\delta), \text{ at } A^*(\delta) \text{ firm I’s market share drops and subsequently increases as } A \text{ expands beyond } A^*(\delta), \text{ and exceeds firm E’s market share when } A > A^I(\delta).\n
Proof: See Appendix.

Proposition 3 states that we can observe a non-monotonic relationship between the level of complementary assets and firm I’s market share for a given level of \delta when the complement-disrupting trajectory is preferred by the market. This result has two conceptual drivers. One is a switch in "regime"
(choice of complement-preserving or complement-disrupting trajectory) and the other is the marginal impact of changes in complementary assets on performance within the same regime. As a result, an increase in $A$ may lead to a jump shift downward in performance with the change in regime and then further increases lead to incremental increases in market outcomes within a given “regime”. Specifically, when the level of complementary assets is low, it is not worthwhile for the incumbent to choose the complement-preserving trajectory. Therefore, the incumbent chooses the complement-disrupting trajectory and in some sense becomes equivalent to the entrant. As the level of complementary assets increases to an intermediate level, however, the incumbent switches to the complement-preserving trajectory. Now, when the complement-disrupting trajectory is preferred, clearly the incumbent will be penalized, ex post, should the market prefer the complement-disrupting trajectory. However, note that such penalty is compensated for the possibility, albeit perhaps small, that the complement-preserving trajectory may be preferred. When the level of complementary assets is sufficiently high, the incumbent will do well even if the complement-disrupting trajectory is realized. This strong performance is not the result of the firm being buffered by complementary assets. Rather, the firm’s complementary assets induce the firm to invest in high levels of R&D, resulting in the superior performance. We illustrate this case with a numerical example in Figure 2 ($\delta = 0.8$, $p = 0.7$, $\beta = 1$, $\gamma = 0.5$). As we can see, the incumbent’s market share takes a U-shape with the level of complementary assets when the complement-disrupting trajectory is preferred by the market. This is mostly driven by a sharp drop in sales around $A = 1.2$ (the point at which the incumbent shifts from the complement-disrupting to the complement-preserving trajectory).

In the following analysis, we examine the shape of the three threshold curves identified in Figure 1. Both the equal-market share curve $A^1(\delta)$ (the lower boundary of the white region) and the equal-investment curve $A^0(\delta)$ (the lower boundary of the black region) increase nearly monotonically in Figure 1, because a larger penalty associated with the choice of the less preferred technological trajectory requires a higher level of complementary assets to compensate and generate equal investment incentives and market outcome.\footnote{The equal-market share curve $A^1(\delta)$ increases monotonically. However, there is a slight drop between the upward increasing part and the flat part of the equal-investment curve $A^0(\delta)$. This drop is caused by the exit of the incumbent’s product when the market favors the complement-disrupting trajectory at a critical threshold of $\delta$ such that $2\beta U_1 - \gamma U_E = 2\beta \delta u_1 - \gamma u_E < 0$. As a result, both firms’ investments do not change with $\delta$ as $\delta$ goes to zero.} However, both the equal-trajectory (the upper bound of the dotted region) and the equal-investment lines (the lower bound of the black region) are flat when delta is small enough. This is because when $\delta$ is small, the incumbent does not produce when the market favors the complement-disrupting trajectory due to the fact that $2\beta U_1 - \gamma U_E = 2\beta \delta u_1 - \gamma u_E < 0$. As a result, both firms’ investments do not change with $\delta$ as $\delta$ goes to zero.
The equal-trajectory threshold $A^*(\delta)$ (the upper bound of the dotted region) exhibits an inverse-U shape as the penalty from technical mismatch $\delta$ changes from 1 to 0. This implies that for a lower level of complementary assets $A$, it is less profitable for the incumbent to choose the complement-disrupting trajectory when $\delta$ is either close to 1 or to 0, but more profitable to do so when $\delta$ has a moderate value. While the complement-preserving trajectory is obviously attractive to the incumbent when it can leverage its complementary asset with low mismatch penalty ($\delta$ is close to 1), the complement-preserving trajectory is also attractive to the incumbent when the mismatch penalty is high ($\delta$ is close to 0) because the complement-preserving trajectory better differentiates the incumbent from the entrant and hence would help it dominate the market should the market turn out to favor it.

To illustrate the above intuition, Figure 3a plots the incumbent’s expected profit depending on its trajectory choice. As it shows, while the incumbent’s expected profit decreases as $\delta$ decreases from 1 to 0 if the firm chooses the complement-disrupting trajectory, it is more L-shape in $\delta$ if the firm chooses the complement-preserving trajectory. To help clarify why the incumbent’s expected profit weakly increases as $\delta$ is close to and approaches 0, Figure 3b plots the base utility $U_i$ of the two firms’ products given the market’s trajectory preference, assuming the incumbent chooses the complement-preserving trajectory. As we can see, when $\delta$ is close to 0, the incumbent can profit only when the market prefers the complement-preserving trajectory because in the other case when the market prefers the complement-disrupting trajectory, the incumbent’s product base utility is far dominated by the entrant’s. When the market prefers the complement-preserving trajectory, the incumbent maintains a high level of product base utility as opposed to the reduction in the utility associated with the entrant’s product. This contrast leads to diminishing competitive pressure when $\delta$ is close to and approaches 0 as the incumbent differentiates itself from the entrant by choosing the complement-preserving trajectory.

4.1: Robustness to fungible complementary assets

In the above analysis, we assumed that the incumbent is able to leverage its complementary assets only when it chooses the complement-preserving trajectory and the complement-preserving trajectory is preferred by the market (second to the last column of Table 1). We made this assumption in order to focus on the central mechanism at work in determining firms’ choices and their market outcomes. In this section, we relax this assumption by allowing for a certain degree of fungibility of complementary assets in the complement-disrupting trajectory. The last column of Table 1 presents a general form of the fungibility of complementary assets. If the incumbent chooses the complement-preserving trajectory $r = 0$ but the market prefers the complement-disrupting trajectory $t = 1$, then the incumbent can still leverage its complementary assets but suffers from a discount; that is, the incumbent’s effective
complementary assets becomes $A^{\kappa_1}$, where $0 \leq \kappa_1 \leq 1$. Similarly, if the incumbent chooses the complement-disrupting trajectory $r = 1$, the incumbent can also leverage its complementary assets to a certain degree; that is, the incumbent’s effective complementary assets becomes $A^{\kappa_2}$, $0 \leq \kappa_2 \leq 1$, whether the market prefers the complement-preserving or the complement-disrupting trajectory.\(^9\) We can interpret $\kappa_1$ and $\kappa_2$ as the degree to which complementary assets are trajectory specific. When complementary assets are fully trajectory specific to the complement-preserving trajectory, then $\kappa_1 = \kappa_2 = 0$; that is, the incumbent’s advantage in terms of complementary assets will disappear if the firm chooses the complement-disrupting trajectory, or when the incumbent chooses the complement-preserving trajectory but the market prefers the complement-disrupting trajectory. In contrast, when complementary assets are fully trajectory independent, then $\kappa_1 = \kappa_2 = 1$, and the incumbent’s advantage in terms of complementary assets will be fully retained regardless of its trajectory choice or which trajectory is ultimately preferred by the market.

Our results are in general robust to this more general setup. In particular the black regime that we identified in Propositions 1 and 2 always exists. The black regime characterizes the case when the complementary asset is sufficiently large that the incumbent prefers the complement-preserving trajectory and invests more than the entrant, but the penalty from technical mismatch is sufficiently high (i.e., the value of $\delta$ is sufficiently small) that the effect of the incumbent’s investment greatly diminishes and the entrant would garner more product market success should the complement-disrupting trajectory be preferred. The existence of the black regime persists when $\kappa_1, \kappa_2 > 0$, because $\kappa_1$ and $\kappa_2$ only influence the incumbent’s preference between the two trajectories and determine how large a value of complementary asset $A$ is required to be to turn the incumbent’s preference toward the complement-preserving trajectory.

However, since $\kappa_1$ and $\kappa_2$, the factors that affect the degree to which complementary assets are specific to a given technical trajectory, can influence the incumbent’s trajectory choice, the shape of the regimes in Figure 1 is affected when we allow for a certain degree of fungibility of complementary assets.

A larger value of $\kappa_1$ makes the complement-preserving trajectory more preferable, and hence it leads to higher investment and profit of the incumbent but lower investment and profit of the entrant if the incumbent chooses the complement-preserving trajectory. Therefore, as $\kappa_1$ increases, the region (in the $A$-$\delta$ plane) where the incumbent prefers the complement-disrupting trajectory (the dotted region) shrinks, and the thresholds of equal-investment (the lower boundary of the black region) and equal-market-share (the lower boundary of the white region) decrease. The four figures of Figure 4a show this pattern.

\(^9\) We could further introduce a $\kappa_3$ to separately represent the case when the market prefers the complement-preserving trajectory and the case when the market prefers the complement-disrupting trajectory, but the mechanisms that we show below do not change.
A larger $\kappa_2$ makes the complement-disrupting trajectory more preferable and hence it leads to higher investment and profit for the incumbent but lower investment and profit for the entrant if the incumbent chooses the complement-disrupting trajectory. In contrast to its impact on trajectory choice, $\kappa_2$ does not affect the equal-investment and equal-market share thresholds because these two thresholds only concern what happens should the complement-preserving trajectory be chosen, and if the complement-preserving trajectory is chosen the value of $\kappa_2$ does not affect the outcome (i.e., the two firms’ investment decisions). Therefore, as $\kappa_2$ increases, the dotted region will expand and may ultimately swallow part or all of the grey region. The four figures of Figure 4b show this pattern.

5. CONCLUSION AND DISCUSSION

Complementary assets do not just shield firms from radical technical changes, but also affect investment incentives. While the existing literature has made the important point that complementary assets can, *ex-post*, influence product market and financial outcomes, the potential effect of complementary assets on economic incentives for *ex-ante* investment behavior has been under-explored.

In comparing the behavior of incumbent and entrant firms, we highlight an important distinction between investment intensity and final outcomes. If firms’ R&D capabilities are homogeneous, it would be sufficient to examine only the magnitude of firms’ investment in new technologies, as homogeneous R&D capabilities imply that equal amounts of R&D investment lead to equal likelihoods of success. However, such an implication will not hold when firms’ technical capabilities are heterogeneous and in particular when they can make different choices of their technical trajectories. As a result, strategy research on radical technological change should distinguish between the magnitude of firms’ investments and the likelihood of technical success.

In conjunction, the above two observations can help explain the empirical puzzle that incumbent firms often fail in the face of radical technological change despite their substantial R&D investments. In the face of radical technological change, the existing literature suggests that the incumbent will tend to invest less than the entrant. The dominant explanation of this within the economics literature is that the concern with cannibalization reduces the incumbent’s marginal benefit from innovative activities. The explanation prominent in the strategy field is that the radical technological change reduces the incumbent’s relevant technical capabilities. However, in fact, we often observe incumbent firms aggressively investing in radical innovations. At the same time, in spite of such investments, it is also not uncommon to observe that the incumbent is overtaken by the entrant in terms of technological leadership. However, these investments need not be irrational. The distinct regimes we identify in the analysis provide important insights into this phenomenon. The presence of complementary assets can enhance the incumbent’s ability to appropriate the gains from innovation and in turn create incentives to invest. At the
same time, complementary assets induce the incumbent to choose a technical trajectory that can leverage its complementary assets but may be inherently less promising. Thus, complementary assets create a form of path dependency even if firms are making rational forward looking decisions regarding their investments. Further, our results suggest that the incumbent’s low technological outcomes may be a consequence of its endogenous choice of technical trajectories, and not a consequence of exogenous change of the incumbent’s technical capabilities endowed from the past.

The distinct regimes identified in this study can generate non-linear relationships between technical success and the level of complementary assets. Firms with low level of complementary assets may give up such assets and pursue the complement-disrupting technical trajectory and, in that respect, become equivalent to the new entrant. It is also possible that firms with sufficiently high levels of complementary assets can still dominate the market, even with the choice of a seemingly less promising technological trajectory. However, in a broad range of settings, established firms, with their investment decisions influenced by their existing stock of complementary assets, may choose less promising technological trajectories and suffer adverse product market outcomes as a consequence. It is also important to recognize that complementary assets may be trajectory specific. If complementary assets are trajectory-specific, it makes sense for an incumbent firm to invest, but not in the same qualitative manner as a new firm. In contrast, if they are independent of trajectory, then the established firm should aggressively pursue the more technically promising trajectory. Finally, if the complements are rendered obsolete, the established firm has no basis of competitive advantage relative to the entrant.

Of course, there are a number of limitations to our analysis. First, the dynamic nature of the setting could be enriched. The current study assumes that complementary assets are fixed and therefore treats them as exogenous parameters. It is certainly the case that this factor evolves over time. One could extend the research by examining firms’ investments not only in R&D, but also with respect to investments in complementary assets. The investments along these two dimensions may be made simultaneously or sequentially. Further, we treat the technical capabilities of the firms as being homogenous. In some sense this assumption strengthens our findings as we show that inertia, keeping to a prior technology, may emerge even in the absence of an inherent disadvantage in the new complement-disrupting technology for the incumbent. However, a more general model would allow for the possibility of heterogeneity of technical capabilities, whether as an inherent property of the firm’s “type” or an outcome of prior investment activity.

Second, as discussed in the model setup, a critical assumption is that the market for complementary assets and technical capabilities are imperfect and, as such, an entrant cannot gain access to complementary assets (e.g., through contracting), while the incumbent may not gain access to external technology (e.g., through licensing). Relaxing this working assumption can lead to a fruitful research
avenue that examines the role of licensing or mergers & acquisitions activities between the incumbent and the entrant (Gans, Hsu and Stern 2002, Gans and Stern 2000). Building on the logic of Gans and Stern (2000), in the presence of licensing, alliances, and mergers & acquisitions, complementary assets can increase the incumbent's bargaining power in the licensing process and thereby lower the licensing fee paid to the entrant. The effects of complementary assets on the licensing fees that might be earned by an entrant, in turn, amplify the incumbent’s pre-innovation incentives, as well as its post-innovation returns. Thus, a large stock of complementary assets would still favor the incumbent by enhancing its returns on R&D relative to the entrant. This is ultimately the critical factor underlying our results regarding the rationality of the incumbent’s R&D investments in the face of radical technical change. Furthermore, the choice of technical trajectory in a given domain may impact the cost and effectiveness with which a firm can access and acquire these capabilities in the form of licensing, alliances, and acquisitions (Cohen and Levinthal 1990).

While these are important possible extensions, the current effort provides an important enrichment of our current treatment of the effect of complementary capabilities. Complementary capabilities are not merely asset stocks that buffer firms from competitive dynamics. They are also an important element of the investment context for firms’ R&D decisions. Complementary capabilities can be leveraged to amplify the returns to an existing competitive position, but that act of leverage is not neutral with respect to the direction of the firm’s technical efforts. We highlight some of the tensions between the incentive to leverage and the need to make technologically appropriate choices and suggest how the balance of this tension may help to explain some of the empirical patterns and puzzles that we observe.
Table 1: The utility functions for the entrant’s and the incumbent’s products.

<table>
<thead>
<tr>
<th>Incumbent’s choice: $r \in {0,1}$</th>
<th>Realized market preference: $t \in {0,1}$</th>
<th>Comments</th>
<th>Entrant’s product quality $U_E$</th>
<th>Incumbent’s product quality $U_I$</th>
<th>Generalization with fungible complementary assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r=0$</td>
<td>$t=0$</td>
<td>The incumbent chooses the complement-preserving trajectory and the complement-preserving trajectory is preferred by market. The incumbent can fully leverage complementary assets $A$, and its R&amp;D effort is fully effective. However, the entrant suffers a discount $\delta$ in its R&amp;D effort due to the mismatch of trajectories.</td>
<td>$U_E = \delta u_E$</td>
<td>$U_I = A u_I$</td>
<td>$U_I = A u_I$</td>
</tr>
<tr>
<td>$r=0$</td>
<td>$t=1$</td>
<td>The incumbent chooses the complement-preserving trajectory, but the market prefers the complement-disrupting trajectory. Therefore, the incumbent cannot leverage its complementary assets $A$ and suffers a discount $\delta$ in its R&amp;D effort due to the mismatch of trajectories. The entrant’s R&amp;D effort is fully effective.</td>
<td>$U_E = u_E$</td>
<td>$U_I = \delta u_I$</td>
<td>$U_I = \delta A^\delta u_I$</td>
</tr>
<tr>
<td>$r=1$</td>
<td>$t=0$</td>
<td>The incumbent chooses the complement-disrupting trajectory, but the market prefers the complement-preserving trajectory. The incumbent cannot leverage its complementary assets $A$. Both the incumbent and the entrant suffer a discount $\delta$ in their R&amp;D effort due to the mismatch of trajectories.</td>
<td>$U_E = \delta u_E$</td>
<td>$U_I = \delta u_I$</td>
<td>$U_I = \delta A^\delta u_I$</td>
</tr>
<tr>
<td>$r=1$</td>
<td>$t=1$</td>
<td>The incumbent chooses the complement-disrupting trajectory, and the market prefers the complement-disrupting trajectory. Therefore, the incumbent cannot leverage its complementary assets $A$. The R&amp;D effort for both incumbent and entrant is fully effective.</td>
<td>$U_E = u_E$</td>
<td>$U_I = u_I$</td>
<td>$U_I = A^\delta u_I$</td>
</tr>
</tbody>
</table>
Figure 1 Illustration of Proposition 1: $p = 0.7, \beta = 1, \gamma = 0.5$. This figure is conditional on the case where the complement-disrupting trajectory is preferred by the market:

1. The white region is where the incumbent chooses the complement-preserving trajectory but nonetheless invests more than the entrant and leads in market share.
2. The black region is where the incumbent chooses the complement-preserving trajectory, invests more than the entrant, but has less market share. It is also the region highlighted by Proposition 2.
3. The grey region is where the incumbent chooses the complement-preserving trajectory but invests less.
4. The dotted region is where the incumbent chooses the complement-disrupting trajectory.

Figure 2: Illustration for Proposition 3.
Figure 3: Profits under alternative trajectory choices

(a) Change in the shape of regimes as $\kappa_1$ varies.
b) Change in the shape of regimes as $\kappa_2$ varies.

$p=0.7, \beta=1, \gamma=0.5, \kappa_1=0.4, \kappa_2=0.1$

$p=0.7, \beta=1, \gamma=0.5, \kappa_1=0.4, \kappa_2=0.2$

$p=0.7, \beta=1, \gamma=0.5, \kappa_1=0.4, \kappa_2=0.3$

$p=0.7, \beta=1, \gamma=0.5, \kappa_1=0.4, \kappa_2=0.4$
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Appendix: Proof for the propositions

Let \( D_i(U_j, U_E) \equiv \frac{\partial n_i(U_j, U_E)}{\partial u_i} \) and \( D_c(u_i) \equiv \frac{\partial c(u_i)}{\partial u_i} \). It is straightforward to show that \( D_i(U_j, U_E) \) decrease in \( U_j, j \neq i \). This implies that \( u_{E}^{*}(u_i) \) decreases in \( u_i \), because by assumption \( C(u_E) \) is sufficiently convex such that the profit functions are quasi-concave, i.e., its first order derivative \( pD_E(U_j, U_E) + (1 - p)D_E(U_j, U_E) - D_c(u_E) \) crosses zero only once.

**Lemma 1:** If firm I chooses the complement-disrupting trajectory, in equilibrium the two firms’ investment and expected total profit do not depend on \( A \). If firm I chooses the complement-preserving trajectory, in equilibrium firm I’s (firm E’s) investment and expected profit increases (decreases) as \( A \) increases.

**Proof:** If firm I chooses the complement-disrupting trajectory, its complementary assets \( A \) does not enter firms’ profit functions (per Equation 1) and hence the equilibrium outcome does not depend on \( A \).

If firm I chooses the complement-preserving trajectory, first, we show that firm I’s (firm E’s) investment increases (decreases) as \( A \) increases. To see this, note that the left hand side of the firm E’s first order condition equation \( pD_E(\delta u_i, u_E) + (1 - p)D_E(Au_i, \delta u_E) = D_c(u_E) \) decreases in \( A \). This implies that firm E’s best response \( u_E^{0*}(u_i) \) decreases in \( A \). Second, we examine the first order condition for firm I’s problem, \( pD_I(\delta u_i, u_E^{0*}(u_i)) + (1 - p)D_I(Au_i, \delta u_E^{0*}(u_i)) = D_c(u_I) \). Note that as \( A \) increases \( pD_I(\delta u_i, u_E^{0*}(u_i)) \) increases because \( u_E^{0*}(u_i) \) decreases, and as \( A \) increases \( (1 - p)D_I(Au_i, \delta u_E^{0*}(u_i)) \) increases because \( D_I(Au_i, \delta u_E) \) increases in \( A \) and decreases in \( \delta u_E \). Therefore, we conclude that \( u_I^{0*} \) increases and \( u_E^{0*} \) decreases as \( A \) increases. Finally, we show that if firm I chooses the complement-preserving trajectory firm I’s (firm E’s) profit increases (decreases) as \( A \) increases. This is because

\[
\frac{\partial \sigma_E}{\partial A} = \frac{\partial \sigma_I}{\partial A} + \frac{\partial \sigma_E}{\partial u_I} \frac{\partial u_I}{\partial A} + \frac{\partial \sigma_E}{\partial u_E} \frac{\partial u_E}{\partial A} > 0 \quad \text{(since in equilibrium we have} \quad \frac{\partial \sigma_I}{\partial A} > 0, \frac{\partial \sigma_I}{\partial u_I} = 0, \frac{\partial \sigma_I}{\partial u_E} < 0, \text{and} \quad \frac{\partial u_E}{\partial A} < 0) \text{and} \quad \frac{\partial \sigma_E}{\partial A} = \frac{\partial \sigma_E}{\partial u_I} \frac{\partial u_I}{\partial A} + \frac{\partial \sigma_E}{\partial u_E} \frac{\partial u_E}{\partial A} < 0 \quad \text{(since in equilibrium we have} \quad \frac{\partial \sigma_E}{\partial A} < 0, \frac{\partial \sigma_E}{\partial u_I} < 0, \text{and} \quad \frac{\partial u_I}{\partial A} > 0, \text{and} \quad \frac{\partial \sigma_E}{\partial u_E} = 0). \]

**Lemma 2:** If firm I chooses the complement-preserving trajectory, as \( A \) increases arbitrarily large, in equilibrium firm I’s investment and expected profit increase arbitrarily large, and firm E’s production quantity goes to zero.

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Proof: Since the term $(1 - p)D_I(Au_I, \delta u^*_E(u_I))$ on the left hand side of firm $I$’s the first order condition equation goes to infinity as $A$ goes to infinity, we have $u_I$ goes to infinity as $A$ goes to infinity. Since 
\[ \frac{\delta x_I^0}{\delta A} = (1 - p)u_I D_I(Au_I, \delta u_E) \] and 
\[ D_I(Au_I, \delta u_E) = \frac{\partial u_I}{\partial \beta}, \] when $Au_I \gg \delta u_E$ we have $\Sigma^0_I$ increases and goes to infinity as $A$ increases and goes to infinity. By Lemma 1, as $A$ increases arbitrarily large, firm $E$’s investment amount decreases, this together with the arbitrarily increasing investment of firm $I$ implies that $2\beta U_E - \gamma U_I$ goes to negative infinity and hence that firm $E$’s production quantity goes to zero. 

Lemma 3: If firm $I$ chooses the complement-preserving trajectory and the market prefers the complement-disrupting trajectory, then $q^{0*}_I < q^{0*}_E$ if and only if $\delta u^{0*}_I < u^{0*}_E$. 

Proof: If firm $I$ chooses the complement-preserving trajectory and the market prefers the complement-disrupting trajectory, then $U_I = \delta u_I$ and $U_E = u_E$. It is easy to verify that $q^{0*}_I < q^{0*}_E$ if and only if $2\beta(\delta u^{0*}_I) - \gamma u^{0*}_E < 2\beta u^{0*}_E - \gamma(\delta u^{0*}_I)$. Then, the lemma follows because $2\beta(\delta u^{0*}_I) - \gamma u^{0*}_E < 2\beta u^{0*}_E - \gamma(\delta u^{0*}_I)$ if and only if $\delta u^{0*}_I < u^{0*}_E$. 

Proposition 1: For any $0 \leq \delta \leq 1$, there exist three thresholds $A'(\delta) \leq A^u(\delta) \leq A^l(\delta)$ such that i) if $1 < A < A'(\delta)$, firm $I$ chooses the complement-disrupting trajectory $r=1$ (i.e., $\Sigma^{0*}_I < \Sigma^{1*}_I$), ii) if $A'(\delta) < A < A^u(\delta)$, firm $I$ chooses the complement-preserving trajectory $r=0$ (i.e., $\Sigma^{0*}_I > \Sigma^{1*}_I$) and invests less than firm $E$, iii) if $A^u(\delta) < A < A^l(\delta)$, firm $I$ chooses the complement-preserving trajectory $r=0$ (i.e., $\Sigma^{0*}_I > \Sigma^{1*}_I$), invests more than firm $E$, but does not lead the market (i.e., $q^{0*}_I < q^{0*}_E$) if the market prefers the complement-disrupting trajectory $r=1$, iv) if $A^l(\delta) < A$, firm $I$ chooses the complement-preserving trajectory $r=0$, invests more than firm $E$ and leads the market (i.e., $q^{0*}_I > q^{0*}_E$), even if the market prefers the complement-disrupting trajectory $r=1$. 

Proof: The existence of $A'(\delta)$ is due to the fact that firm $I$’s expected profit increases and goes to infinity as $A$ increases and goes to infinity if firm $I$ chooses the complement-preserving trajectory (Lemmas 1 and 2), while its expected profit does not depend on $A$ if firm $I$ chooses the complement-disrupting trajectory (Lemma 1). The existence of $A^u(\delta)$ is due to the existence of $A'(\delta)$ (i.e., firm $I$ chooses the complement-preserving trajectory when $A > A'(\delta)$) and the following fact: If firm $I$ chooses the complement-preserving trajectory, as $A$ increases and goes to infinity firm $I$’s investment amount increases and goes to infinity (Lemma 2) and firm $E$’s investment amount decreases (Lemma 1). In particular, if firm $I$’s investment is smaller than firm $E$’s when $A$ is arbitrarily close to $A'(\delta)$ from above, we have $A'(\delta) < A^u(\delta)$; otherwise, we have $A'(\delta) = A^u(\delta)$. Similarly, the existence of $A^l(\delta)$ is due to the existence of $A'(\delta)$ and the following fact: If firm $I$ chooses the complement-preserving trajectory and the market prefers the complement-disrupting trajectory, as $A$ increases and goes to infinity, firm $I$’s production
quantity increases (by Lemma 1) and firm $E$’s production quantity decreases and goes to zero (Lemma 2). The ordering $A^u(\delta) \leq A^l(\delta)$ is due to the definitions of these two thresholds and the fact that firm $I$’s investment monotonically increases as $A$ increases if firm $I$ chooses the complement-preserving trajectory (Lemma 1). In particular, if $A^r(\delta) < A^u(\delta)$ we must have $A^u(\delta) < A^l(\delta)$ because we have $\delta u^0_I < u^0_E$ (and hence $q^0_I < q^0_E$) by Lemma 3 when $A = A^u(\delta)$ (by definition of $A^u(\delta)$) and the market prefers the complement-disrupting technical trajectory; however, if $A^l(\delta) = A^u(\delta)$, we have $A^u(\delta) = A^l(\delta)$ if and only if $q^0_I > q^0_E$ when $A$ is close to $A^u(\delta)$ from above and the market prefers the complement-disrupting technical trajectory.

**Lemma 4:** Suppose firm $I$ chooses the complement-preserving trajectory. For any $A > 0$, there exists $\delta(A) > 0$ such that for all $\delta < \delta(A)$, $\delta u^0_I < u^0_E$ in equilibrium.

Proof: The lemma is true because as $\delta$ goes to zero, the firms’ equilibrium investments $u^0_I$ and $u^0_E$ are given by $(1 - p)D_I(Au_I, 0) = D_c(u_I)$ and $pD_E(0, u_E) = D_c(u_E)$, and are both positive. Thus, we have $\delta u^0_I < u^0_E$ for all $\delta$ small enough.

**Proposition 2:** For any $0 \leq \delta < 1$, there exists $0 < \bar{p}(\delta) < 1$ such that $A^r(\delta) > 1$ when $p > \bar{p}(\delta)$. There exists $\delta > 0$ such that for all $\delta < \delta$, $A^u(\delta) < A^l(\delta)$.

Proof: For any $0 \leq \delta < 1$, there exists $0 < \bar{p}(\delta) < 1$ such that $A^r(\delta) > 1$ when $p > \bar{p}(\delta)$ because when $p$ equals 1 it is straightforward to show that $u^0_I < u^*_I$, $u^0_E > u^*_E$, and $C(u^*_I) > C(u^*_E)$. According to Lemmas 4 and 3, there exist a threshold $\delta > 0$ such that $A^l(\delta) < A^u(\delta)$. According to the proof of Proposition 1, $A^r(\delta) < A^l(\delta)$ implies either $A^r(\delta) < A^u(\delta)$ or $A^u(\delta) = A^l(\delta)$ where $A^u(\delta)$ is a constant as $A$ expands beyond $A^r(\delta)$, and exceeds firm $E$’s market share when $A > A^l(\delta)$.

**Proposition 3:** There exists $0 < \delta < 1$ such that when $0 < \delta < \delta$, $p > \bar{p}(\delta)$, and the complement-disrupting trajectory is preferred by the market, firm $I$’s market share is non-monotonic as $A$ increases from 1 to arbitrarily high levels. In particular, firm $I$’s market share is constant with respect to its level of complementary assets when $A < A^r(\delta)$, at $A^r(\delta)$ firm $I$’s market share drops and subsequently increases as $A$ expands beyond $A^r(\delta)$, and exceeds firm $E$’s market share when $A > A^l(\delta)$.

Proof: Proposition 2 implies that when $\delta < \delta$ firm $I$’s market share increases as $A > A^r(\delta)$ increases and exceeds firm $E$’s market share when $A > A^l(\delta)$. When $A < A^r(\delta)$, the incumbent chooses the complement-disrupting trajectory, and its market share is a constant as $A < A^r(\delta)$ increases because the
firms’ equilibrium investment does not depend on $A$ (by Lemma 1). Denote the market share of the incumbent by $R_u$.

As $\delta$ goes to zero, $U_t = \delta u_t^0*$ goes to zero when $A$ approaches $A^r(\delta)$ from above; therefore, there exists a threshold $\delta > 0$ such that for all $\delta < \delta$ we have $q_t^0*/(q_t^0* + q_t^0)$ < $R_u$ when $A$ approaches $A^r(\delta)$ from above. Let $\delta = \min \{\delta, \delta\}$. Therefore, when $0 < \delta < \delta$ and $p > \bar{p}(\delta)$, we have $1 < A^r(\delta) < A^l(\delta)$ and firm $I$’s market share is a constant when $A < A^r(\delta)$, drops below the constant when $A$ exceeds $A^r(\delta)$, increases as $A > A^r(\delta)$ increases, and exceeds firm $E$’s market share when $A > A^l(\delta)$. ■