Research Report: Disruptive Technologies—Explaining Entry in Next Generation Information Technology Markets

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The most difficult challenge facing a market leader is maintaining its leading position. This is especially true in information technology and telecommunications industries, where multiple product generations and rapid technological evolution continually test the ability of the incumbent to stay ahead of potential entrants. In these industries, an incumbent often protects its position by launching prematurely to retain its leadership. Entry, however, happens relatively frequently. We identify conditions under which an entrant will launch a next generation product thereby preventing the incumbent from employing a protection strategy. We define a capabilities advantage as the ability to develop and launch a next generation product at a lower cost than a competitor, and a product with a greater market response is one with greater profit flows. Using these definitions, we find that an incumbent with a capabilities advantage in one next generation product can be overtaken by an entrant with a capabilities advantage in another next generation product only if the entrant's capabilities advantage is in a disruptive technology that yields a product with a greater market response. This can occur even though both next generation products are available to both firms. We also show that the competition may require the launching firm to lose money at the margin on the next generation product.
(*Competitive Strategy*; *Defensive Strategy*; *Disruptive Technology*; *Game Theory*; *Product Research*)

1. Introduction

The most difficult challenge facing a market leader is maintaining its leading position. This is especially true in information technology (IT) and telecommunications industries, where multiple product generations and rapid technological evolution continually test the ability of the incumbent (the current market leader) to stay ahead of potential entrants. Firms such as Intel, Hewlett Packard, and Motorola have maintained their lead over several product generations by "eating their own lunch": launching products which cannibalize their current leading products. Intel's introduction of the 486, Pentium, and P6 microprocessors are classic examples whereby each successive launch solidified its position as market leader while cannibalizing its previous generation.

Maintaining leadership through cannibalization is becoming a well-accepted strategy by both managers and academics—especially in hotly contested markets (Deutschman 1994). D'Aveni (1994) argues that advantages in these hypercompetitive markets can be sustained only by a series of preemptive moves designed to stay ahead. Nault and Vandenbosch (1996) show that even when accounting for cannibalization, incumbents should protect their position against potential entrants by launching earlier than they would without

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competition—protection through preemption, possibly losing money at the margin in order to protect its leading position.[1]

Notwithstanding the apparent success of incumbent preemption, Klepper (1996) has shown that during periods of market growth, entrants have been found to account for a disproportionate share of product innovation in a wide variety of industries. This suggests that changes in leadership resulting from market *entry* happen frequently. There are several arguments that support entry. One argument is that entry occurs because incumbents make mistakes, either by underestimating potential entrants, or through sluggish product development and launch processes. However, the frequent entry observed empirically is unlikely to be a result simply of mistakes made by a series of incumbents across industries. A second argument supporting entry is that entrants have superior capabilities, sufficient to outweigh the advantage of incumbency. Though possible, there remains a question as to why entrants would have significantly better capabilities than incumbents, especially in the incumbent's arena. A third argument supporting entry is that market uncertainty leads incumbents to choose inappropriate development paths. This argument should lead to some situations where incumbents fall to entrants. However, given the advantages to incumbency (financial power and market access), entry due to the outcomes of decisions under uncertainty should not lead to the levels of entry currently observed. A final argument supporting entry is that technological change favors the entrant. That is, the entrant's capabilities advantage is due to the use of new technology which is unavailable to the incumbent. Although this notion has some merit, the relative ease with which intellectual and technological capital can be acquired implies that the incumbent's capabilities are unlikely to be so far behind the entrant that technology differences *alone* would allow the entrant to dominate the incumbent.

Nault and Vandenbosch (1996), in a model which focuses on the advantages due to incumbency, show that preempting your own market-leading product is an equilibrium strategy for the incumbent. As a consequence, the incumbent always preempts the entrant. In this paper, we develop a similar model, but one that can explain the empirical frequency with which entry occurs. To do this, we employ two new aspects related to innovative features that we believe typify the IT and telecommunications industries. The first is endowing firms with capabilities advantages so that one firm can launch a given next generation product more profitably than another. The second is allowing different next generation products to have different levels of market response. In this way, we combine features of technological change favoring the entrant with the nature of market response to show that, under certain circumstances, entrants with only *moderate* capabilities advantages can be first to launch a next generation product. Specifically, for entry to occur, the entrant must have a capabilities advantage in the next generation product with the greater market response. In the process, the entrant prevents the incumbent from employing a preemption strategy. We also show that winning this competition for market leadership may require the entrant to lose money at the margin on the next generation product.

The manner in which these features interact to allow entry is best illustrated through an example. Prior to the advent of cellular phones, AT&T was the recognized leader in wired telephone handsets. As the telephone handset advanced, AT&T was at the forefront in the implementation of new telephone features. However, when cellular phones were developed, essentially a next generation telephone with a wireless feature, AT&T was unable to use its incumbent advantages to lead in that new market segment. Motorola, with its expertise in wireless communications, had a slight capabilities advantage over AT&T. At the time, AT&T was developing cellular technology and had the resources to buy in the capabilities it needed. We argue that it was the moderate capabilities advantage *plus* the nature of profits available to the first-mover in the cellular market that allowed Motorola to overcome AT&T's incumbent advantages and enter successfully.

[1]Early analytical research also supported incumbency. In this work, rather than launching first, incumbents deter entry with investment in excess capital (Spence 1977, 1979; Dixit 1979, 1980; Eaton and Lipsey 1980; Fudenberg and Tirole 1983). Later research, supporting entry, shows that because the incumbent will damage its current rents by launching the next generation, the entrant has less to lose and is compelled to launch first (Kamien and Schwartz 1982; Reinganum 1983, 1985; Ghemawat 1991).

Table 1 **Nominal Profit Flows from the Current and Next Generation Products**

Firm	Current Product	Firm	Extension	Disruption
Incumbent	$\pi_1(t)$	Leader	$\varepsilon_1^i(t)$	$\delta_1^i(t)$
Entrant	$\pi_2(t)$	Follower	$\varepsilon_2^i(t)$	$\delta_2^i(t)$
Simultaneous	$\pi_3(t)$	Simultaneous	$\varepsilon_3^i(t)$	$\delta_3^i(t)$

Though AT&T remained the leader in the basic handset market, it is still struggling to catch up in the wireless market. In this example, the next generation product helped create a new leader in a relatively distinct market segment with limited cross-market cannibalization with the original market. Other examples—including Matsushita overtaking Ampex and Sony in video cassette recorders and Nintendo overtaking Atari in video game players (Grant 1995)—illustrate that in some industries, the entrant's strategy can allow them to become the overall market leader.[2]

The remainder of the paper is organized as follows. In the next section, we describe our model formulation, definitions, and assumptions. Then, we provide the details of our model and report our main results. The final section presents a discussion of the results and managerial implications.

2. Formulation, Definitions, and Assumptions

We model the rivalry between an incumbent, who may be the market leader in the current generation, and an entrant, who may also have a current generation product. The two firms compete to launch a next generation product.[3] Competitors choose between two next generation products. Essentially, these products represent the "best" two options for future development of the market. Allowing for two types of next generation products means that the incumbent and entrant may differ in their ability to produce a specific next generation product. Therefore, it is useful to describe these products as being based on different technologies. We describe one product as an *extension.* This product is the next generation option that extends the features of the current product using refinements to technologies that have been employed in the past. The incumbent is likely to have an advantage in this arena as the resources and capabilities it used to gain its current position should persist. The second product, based on an alternative technology, is described as a *disruption.* Here, there is a greater possibility that the entrant can have a capabilities advantage over the incumbent. Extending the AT&T/Motorola telephone example, the extension could be a new feature—such as call waiting—that is added to the wired telephone handset, whereas the disruption would be the cellular telephone.[4]

According to Bower and Christensen (1995), disruptive technologies introduce a new package of features to the market which have the potential to change the nature of competition. Often, the initial products based on these disruptive technologies do not meet some of the performance needs of current customers (e.g., the voice quality of early cellular telephones), but offer other important features (e.g., wireless) which other customers desire. As such, these products are typically used in new applications and make possible the emergence of new markets or segments. Utterback (1995) argues that regardless of how well a firm is positioned in the market, technological development leads to situations where the capabilities of the incumbents are insufficient to sustain attacks from companies that champion these disruptive technologies because producing products from these technologies requires a different set of capabilities.

In developing our model, we use the profit flow notation in Table 1. Product profit flows for the current generation are represented by π, for the extension by ε, and for the disruption by δ. For the extension and

[2]Yet other examples include X-ray CT scanners (General Electric over EMI), personal computers (IBM over Xerox), and pocket calculators (Texas Instruments over Bowmar) (Grant 1995).

[3]Our formulation and results depend only on the incumbent and the strongest entrant. As such, our model can accommodate any number of competitors.

[4]No inference should be made that software-based enhancements are extensions rather than disruptions. In many instances, product enhancements such as Cognos developing a web version of its market leading Powerplay OLAP software have much more impact than a competitor launching products based on a different paradigm.

the disruption, we represent the incumbent in the current generation by superscript I and the entrant by superscript E so that $i \in \{I, E\}$. For reasons that will be apparent shortly, the profit flows in Table 1 do not include the fixed costs of development and launch. In addition, profit flows are nominal, so where necessary we discount them using a positive discount rate, $r > 0$.

The profit flows from the current product are $\pi_1(t)$ for the incumbent, $\pi_2(t)$ for the entrant, and $\pi_3(t)$ if the most recent launch was simultaneous. If firm i launches the extension, then i's profit flow from leading is $\varepsilon_1^i(t)$, from following is $\varepsilon_2^i(t)$, and is $\varepsilon_3^i(t)$ if there is a simultaneous launch. Similarly, if i launches the disruption, then i's profit flow from leading is $\delta_1^i(t)$, from following is $\delta_2^i(t)$, and is $\delta_3^i(t)$ if there is a simultaneous launch.

We use T as the launch time and assume that only one of the two types of new products can be launched by a given firm prior to some fixed barrier $\bar{T}$, analyzing the period between the current time ($T = 0$) and $\bar{T}$. This restriction delineates one generation from the next.

To further elaborate on our model, we provide three definitions that will be used to govern our analysis. In keeping with past literature, we define our incumbent and entrant based on what Katz and Shapiro (1987) refer to as the incentive to preempt.[5]

Definition 1 (Incentive to Preempt). The *incumbent* is the firm with the largest difference in the present value of profit flows between having launched the next generation product and being preempted by a competitor. Ordering firms by this difference, the *entrant* is the firm with the next largest difference.

For example, Intel, the market leader with 80 percent share of the PC microprocessor market, would be the incumbent because it has the most to lose from being preempted by an entrant with a superior PC microprocessor. The incentive to preempt ordering can be considered as the advantage that an incumbent has because of its current market position. This advantage may be due, for example, to the effects of learning, economies of scale, or market access, and is present regardless of which next generation product is considered.[6] The incentive to preempt not only identifies the incumbent and entrant, but also indicates the *degree* to which there is an incumbency advantage. If there is one major player in an industry, then their incentive to preempt is large because an entrant's gains will most likely come at the expense of that major player. In an industry like the ATM switch market, where there are several similar sized players (Fore Systems, Cisco Systems, Nortel, Newbridge Networks, 3COM), an entrant's gains come at the expense of each competitor. As a result the difference between the incentives to preempt for the incumbent and entrant is smaller.

Two types of next generation products allows differences in market response. Our second definition orders the profits available from the next generation products.[7]

Definition 2 (Market Response). Profits from launching the disruption are greater than from launching the extension.

Definition 2 holds when the disruption is more differentiated from the current product than is the extension, and profits can be gained from the greater differentiation (see Vandenbosch and Weinberg 1995). If features related to the disruptive technology are different than those in the current product, then new opportunities may be created that would not be available if the next generation product only improved features of the existing technology. For example, cellular phones disrupted the wired telephone market by opening up new demand for telephones among traveling salespersons and busy executives. Similarly, the 3.5-inch hard disk drive enabled the rapid growth of the portable computer market, and the ink jet printers opened up a huge personal printer segment. This definition is further supported by the empirical evidence citing the advent of disruptive technologies leading to

[5]Where not provided in the text, the mathematical form of our definitions and assumptions are available in the mathematical appendix.

[6]We do not restrict whether the incumbent is facing the same entrant in each next generation product (extension and disruption) since the entrant in each next generation product is defined by the incentive to preempt, and the launch time of the entrant with the disruption and the entrant with the extension are never directly compared.

[7]Our formulation makes no assumptions regarding the absolute or relative market size, or adoption rates of either next generation product.

the implementation of new features as the chief source of major market shifts (Bower and Christensen 1995).

Our third definition focuses on the role of resources and capabilities in determining the firms' relative advantages. Following from the literature on the resource-based view of the firm (Wernerfelt 1984, Barney 1991) and capabilities (Teece et al. 1997, Prahalad and Hamel 1990, Grant 1991), we contend that firms have differential advantages in their ability to compete in next generation markets. These differential advantages can result from differences in access to relevant resources and/or differences in organizational routines/processes that convert resources into capabilities (Amit and Schoemaker 1993). In addition, these resources and capabilities are difficult to replicate, especially in the short term (Dierickx and Cool 1989). Teece et al. (1977) use the term "dynamic capabilities" to describe how in changing environments "combinations of competencies and resources can be developed, deployed and protected" (p. 510). They argue that "the competitive advantage of firms lies with its managerial and organizational processes, shaped by its [resource] position, and the paths available to it" (p. 518). In our context, this implies that the degree to which the incumbent and entrant can effectively compete with either the extension or the disruption is dependent on the nature of the firm's routines/processes (e.g., product development, benchmarking, learning), resources (e.g., intellectual property, specialized plant and equipment), and development paths (e.g., product platform, customers served). For the purpose of our model, we describe these differential advantages that firms have as capabilities advantages.

Given the preceding discussion, it is clear that a capabilities advantage can result from a variety of resources, processes, and situations. However, the objective of utilizing these capabilities to implement strategies that improve efficiencies and effectiveness is the same regardless of the source of the advantage (Barney 1991). The improved effectiveness and efficiencies result from the ability of capable firms to execute the routines associated with innovation, development, and other launch activities at a lower cost than their less capable competitors. Accordingly, we model capabilities advantages by endowing firms with differential launch costs. As such, they can lead to differences in the profits from the next generation products. Launch costs, in this context, include all of the costs required to bring a new offering to market. With this definition, launch costs capture the differential resources of the firms such as intellectual property or customer access as well as the internal application of routines such as environmental scanning, benchmarking, product development, learning, product launch, and marketing.

To formalize this, let $K_\varepsilon(t)$ and $K_\delta(t)$ represent the present value of the cost of launching the extension and the disruption at time t, respectively. To ensure that one firm does not trivially dominate the other, we endow each firm with a capabilities advantage in a different next generation product.

Definition 3 (Capabilities Advantage). $K^i_\varepsilon(t) < K^l_\varepsilon(t)$ and $K^l_\delta(t) < K^i_\delta(t)$, where $i, l \in \{I,E\}$ and $i \neq l$.

From Definition 3, a firm with a capabilities advantage can launch a given next generation product at a lower cost than a competitor that does not have that capabilities advantage.[8] We could alternatively define the advantage in terms of increased profit flow from the launch of a product in which the given firm has the capabilities advantage. However, the delivered next generation product would be the same regardless of the firm launching the product, and therefore, a profit flow-based capabilities advantage would rely heavily on variable cost differences between the competitors. Because products in the IT and telecommunication industries tend to have high fixed (e.g., a fab plant) and low variable costs (e.g., materials), a launch cost advantage better captures the essence of the capabilities advantage. Moreover, differences in fixed costs are usually determined by relative firm capabilities, whereas variable costs are often market-driven. Using costs to model interfirm differences is not unusual. For example, Lippman and Rumelt (1982) operationalize interfirm differences stemming from uncertain imitability by modeling a parameter of a firm's cost function as a random variable.

We require a set of three basic assumptions similar to Nault and Vandenbosch (1996). The first specifies the curvature of launch costs over time. The second

[8]For strategy literature showing that timing of entry, linked to lower costs, has a basis in firm capabilities see Lieberman and Montgomery (1998) and Schoenecker and Cooper (1998).

specifies the type of competitive interaction and the third ensures that there is an interior solution to the problem.

Assumption 1. *The nominal cost of launch falls over time at a decreasing rate.*

Assumption 2. *The interaction between the firms and the market is characterized by Bertrand competition.*

Assumption 3. (a) *No firm launches immediately,* (b) *the next generation is launched in finite time.*

Assumption 1 reflects the notion that the tools and skills necessary to successfully complete R&D on a specific technology improve and are more widely disseminated with time. These tools and skills, whether product or process related, reduce the current cost of product development and launch. There are a number of factors which make Assumption 1 reasonable including the practice of reverse engineering, rapid and widespread dissemination of scientific information, and the trends toward efficient channels of distribution of both products and promotional material. Assumption 1 is also consistent with the high cost of "crashing" development projects as compared to completing them on a normal schedule.

Competition under conditions of high fixed and low marginal costs is best modeled as Bertrand (Tirole 1988). Bertrand competition—our Assumption 2—implies that firms compete in prices rather than in quantities, and prices above marginal cost (hence positive profits) can only be achieved through product differentiation.[9] In our modeling environment, this restricts the profits that can accrue to the follower in the next generation. This is because if both firms' next generation products were the same, then prices would be competed down to marginal cost and profits from the next generation would be zero. Moreover, the lower prices resulting from the intensity of competition in the next generation would reduce profits from the current product by a greater amount (because it has to compete with the next generation product prices) than if just one firm launched the next generation and monopoly prices obtained in that generation product (Ghemawat 1991, Judd 1985).[10] Thus, there is a significant first-mover advantage. In many advanced technology markets, leaders exercise this advantage by adjusting their marketing variables to make the market less attractive to entry. For example, both AMD and Cyrix, followers in the Pentium microprocessor market, announced losses as a result of "aggressive pricing" by Intel (Gomes 1996). Intel's tactics appear to have led to reduced margins with no reduction in fixed costs.

Assumption 3 focuses our attention on the interaction of firms over time rather than the extreme cases where one firm would launch immediately or where the next generation would never be launched.

3. Model

3.1. Features of the Equilibrium Solutions

We use "games of timing" developed by Fudenberg and Tirole (1985) to generate our solution, an approach that we find especially relevant for fast-paced IT and telecommunications markets where methods to improve product development cycle time and speed to market are widespread (Gaynor 1993, Patterson 1993). In these models firms' launch costs and profit flows are common knowledge. The features of our equilibrium solutions parallel those in Nault and Vandenbosch (1996):[11]

• There is not a second launch of the next generation product. This feature results from Bertrand competition. For example, the president of AUCNET, an IT and

[9]The alternative is the Cournot model in which firms choose quantities rather than prices. The key assumption in that model is scale economies in production: at some output level the marginal costs of production become large. In IT and telecommunications marginal costs remain low as output expands, and thus the Cournot model is not realistic. The Cournot model has also been criticized because even though firms may begin by choosing quantities, they must ultimately choose prices to equate supply and demand (Tirole 1988).

[10]Technically, our model requires conditions that are less restrictive than those implied through Bertrand competition. In other words, if Bertrand competition and its implications were not true, our results could still hold. Specifically, even if there are positive profits from following or a simultaneous launch (which would contradict the Bertrand assumption), as long as these profits do not outweigh the launch costs our results still hold.

[11]That our equilibrium satisfies the conditions required for existence and uniqueness is shown in the mathematical appendix. The remaining proofs that the equilibrium features hold are available from the authors.

telecommunications-based auction network system for used automobiles started in Japan, stated that *"in the network business, there is always a first-mover, and never the second"* (Harvard Business School 1990, 7).[12]

• There is not a simultaneous launch from both firms. Bertrand competition in the same good yields marginal cost pricing, which in turn depresses price for related products. Thus, we can eliminate a simultaneous launch from consideration because simultaneous launch is dominated by both leading and following.[13]

• There is a unique time for each firm and each next generation product when the firm is indifferent between leading and following, and after which leading is more profitable than following.

The equilibrium solutions to the model can be found by comparing the critical times when firms are indifferent between leading and following.[14] Payoffs for the incumbent launching the extension at time T are

$$L_\varepsilon^I(T) = \int_0^T \pi_1(t)e^{-rt}\,dt + \int_T^{\bar{T}} \varepsilon_1^I(t)e^{-rt}\,dt - K_\varepsilon(T)$$

and

$$F_\varepsilon^I(T) = \int_0^T \pi_1(t)e^{-rt}\,dt + \int_T^{\bar{T}} \varepsilon_2^I(t)e^{-rt}\,dt,$$

where the follower's payoff does not include launch costs as no second launch occurs. Similar functions can be obtained for the incumbent with the disruption, and for the entrant with the extension or the disruption where profit flows from the current product are $\pi_2(t)$ rather than $\pi_1(t)$. Using this information we can find the critical times when payoffs to leading equal the payoffs to following, that is, when $L_\varepsilon^i(T) = F_\varepsilon^i(T)$ and $L_\delta^i(T) = F_\delta^i(T)$.

[12]Though there is no second next generation product, we do not preclude the possibility that the follower could be the leader in a future generation, subsequent to the next generation we study. In addition, there could still be profit flows that accrue from the diffusion of previous generations.

[13]Prior research has also ruled out simultaneous launch as equilibria in these types of models (Fudenberg and Tirole 1985, Reinganum 1981).

[14]This type of equilibrium is a preemption equilibrium because the *leader* launches the next generation product earlier than it would in the absence of competition (i.e., before the peak of the profit function).

For the extension those times are defined by

$$T_\varepsilon^i\colon L_\varepsilon^i(T_\varepsilon^i) = F_\varepsilon^i(T_\varepsilon^i) \Rightarrow \int_{T_\varepsilon^i}^{\bar{T}} [\varepsilon_1^i(t) - \varepsilon_2^i(t)]e^{-rt}\,dt - K_\varepsilon(T_\varepsilon^i) = 0,$$

and for the disruption they are defined by

$$T_\delta^i\colon L_\delta^i(T_\delta^i) = F_\delta^i(T_\delta^i) \Rightarrow \int_{T_\delta^i}^{\bar{T}} [\delta_1^i(t) - \delta_2^i(t)]e^{-rt}\,dt - K_\delta(T_\delta^i) = 0.$$

3.2. Analysis Framework

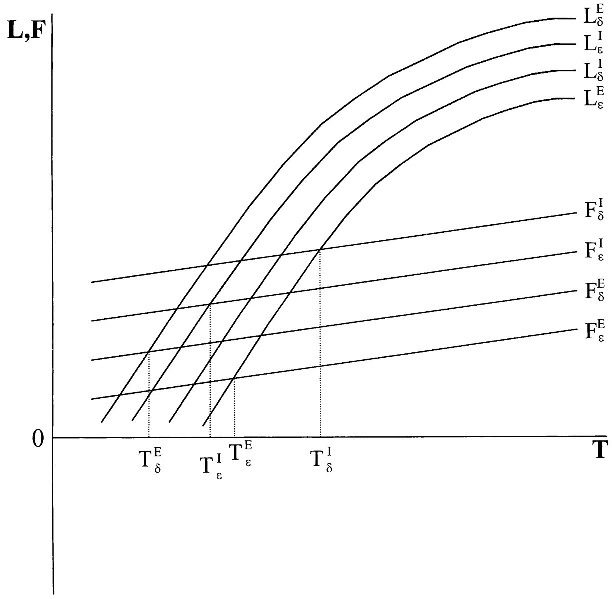
Our model focuses on the importance of a capabilities advantage and a differential market response in allowing entry to occur. A third feature that enters into the analysis is the incumbent's incentive to preempt. This incentive gives the incumbent an initial advantage in the next generation competition. As shown in Table 2, there are four sets of equilibrium solutions depending on the setting. Our detailed results pertain only to Cell 4. The solutions in the other cells are straightforward and are described below.

In Cell 1, there are no capabilities advantages and no differences in market response between the next generation products. This cell describes the Nault and Vandenbosch (1996) model. Under these conditions, incumbent preemption will always be the equilibrium outcome and the incumbent will maintain leadership in the next generation. In Cell 2, there are no capabilities advantages, but there are differences in market

Table 2 **Analysis Framework**

		Differential Market Response	
		No	Yes
Capabilities Advantage Exists	No	*Cell 1:* Incumbent Preemption (Nault and Vandenbosch 1996)	*Cell 2:* Incumbent Preemption
	Yes	*Cell 3:* Incumbent Preemption will dominate, but if the Entrant has a huge capabilities advantage, entry is possible	*Cell 4:* Entrant Preemption possible if Entrant has a capabilities advantage with the disruption

Figure 1 Leader and Follower Functions Illustrating Entry



response. Since the incentive to preempt favors the incumbent and both competitors have equal capabilities, the equilibrium solution will have the incumbent launching the disruption, the next generation product with the greatest market response.

In Cell 3, there are capabilities advantages, but there are no differences in market response between next generation products. We only look at the case when each firm has a capabilities advantage on a different next generation product. Assume that the incumbent has an advantage with the extension and the entrant has an advantage with the disruption.[15] Since there are no market response advantages in this case, for the entrant to successfully enter it must have a much larger advantage over the incumbent with the disruption than the incumbent advantage over the entrant with the extension. The "extra" advantage is to overcome the incumbent's incentive to preempt. Because intellectual capital is difficult to keep, proprietary and technological capital can be purchased—we would argue that entry under these conditions would be infrequent.

3.3. Capabilities Advantage and Market Response

In Cell 4, both the capabilities advantage and differential market response matter. By the way we scale and define the two different next generation products, we equalize the corresponding launch costs between the two firms for the products in which they have capabilities advantage. For example, if the entrant has capabilities advantage in the disruption and the incumbent has capabilities advantage in the extension, then we scale the launch costs so that $K^E_\delta(t) = K^I_\varepsilon(t)$. This scaling of launch costs, together with our definition of market response, means that one next generation product does not trivially dominate the other. Each firm can launch either next generation product, and from Definition 3 a given firm has a capabilities advantage in only one next generation product.

3.3.1. Entrant Has Capabilities Advantage with the Disruption If the entrant has the capabilities advantage with the disruption, then the incumbent has the capabilities advantage with the extension. The next lemma partially orders the times when payoffs to leading are equal to those from following.[16]

Lemma 1. *If* (a) *the capabilities advantage with the disruption is greater than the incentive to preempt with the disruption, and* (b) *the difference in profits between leading and being preempted with the disruption for the entrant are greater than the difference between leading and being preempted with the extension for the incumbent, then* $T^E_\delta < T^I_\delta$, T^I_ε *and* $T^I_\varepsilon < T^E_\varepsilon$.

For the entrant to lead in the next generation market, its indifference time between leading and following with the disruption must be earlier than for the incumbent with either product. If the disruption has a much greater market response, then the incumbent's best option may be to attempt to develop the disruption. The ability of the entrant to lead is based on the size of its capabilities advantage relative to the incumbent's incentive to preempt with the disruption (condition (a) in the lemma). If, on the other hand, the incumbent's best strategy is to concentrate on the extension, the capabilities advantages and incentive to preempt become less important. Instead, the ability of the entrant to lead is based upon the size of the market response difference between the two next generation products (condition (b) in the lemma). Figure 1 illustrates the leader

[15]Similar results hold if the product assignment is reversed.

[16]Proofs of the lemmas and theorems are available in the mathematical appendix.

and follower functions for the two firms under Lemma 1 when $T_\varepsilon^I < T_\delta^I$ (i.e., the incumbent's best strategy is to concentrate on the extension) and the equilibrium is preemptive.[17]

Theorem 1. *If* (a) *the capabilities advantage with the disruption is greater than the incentive to preempt with the disruption, and* (b) *the difference in profits between leading and being preempted with the disruption for the entrant are greater than the difference between leading and being preempted with the extension for the incumbent, then the unique perfect preemption equilibrium is when the entrant launches the disruption at the minimum of T_δ^I and T_ε^I.*

Theorem 1 provides conditions under which entry occurs. This entry does not occur because the incumbent is preoccupied with cannibalization. Rather, the entrant launches preemptively in order to thwart the incumbent's efforts to maintain market leadership. Thus, the entrant's capability advantage in the disruptive technology allows it to take advantage of the disruption's greater response. This is precisely how transitions from one dominant technology to the next have been documented (Foster 1985, Utterback 1995, Bower and Christensen 1995).

In many situations, the conditions in the theorem are realistic. The lower the incumbent's incentive to preempt with the disruption, the easier it is to satisfy condition (a) and the smaller the capabilities advantage required by the entrant. In situations where several competitors hold similar sized market shares, it would be expected that the incumbent's incentive to preempt would be smaller. This is true in a wide range of industries, like the PBX, laptop computer, and disk drive industries, that have seen significant technology "leapfrogging" behavior. A low incentive to preempt with the disruption could also occur when the next generation product opens up a new segment that does not significantly affect the diffusion process in the original market. In this case, the incumbent is unlikely to "lose" a significant portion of its current rent stream. The introduction of cellular telephones may fit this scenario.

The larger the difference in market response between next generation products, the easier it is to satisfy condition (b). We argue that there are many situations where the market response from the disruption is significantly larger than from the extension. For example, leading portable computer manufacturers (e.g., Toshiba), anxious to exploit a large untapped market segment, were pushing for smaller hard drives in advance of the development of the 3.5-inch drive.

[17]If the entrant's payoffs to leading with the disruption are sufficiently larger than the other payoffs, then the entrant's optimal time to launch the disruption is prior to any of the other critical times, and the equilibrium is not preemptive. We concentrate throughout on the more competitive situations where the equilibria are preemptive.

3.3.2. Incumbent Has Capabilities Advantage with the Disruption The second case in Cell 4 of Table 2 gives the incumbent the capabilities advantage with the disruption and the entrant the capabilities advantage with the extension. We state the lemma giving a partial ordering of the critical times and the corresponding theorem below. The proof of Lemma 2 is similar to that of Lemma 1.

Lemma 2. *If the difference in profits between leading and being preempted with the disruption for the entrant are greater than the difference between leading and being preempted with the extension for the incumbent, then $T_\delta^I < T_\delta^E, T_\varepsilon^I, T_\varepsilon^E$.*

Lemma 1 required a condition that the capabilities advantage yielded launch costs advantages that were sufficiently large in favor of the entrant as to overcome the incumbent's incentive to preempt. Lemma 2, on the other hand, does not because the incumbent has the capabilities advantage in the disruptive technology as well as the incentive to preempt.

Theorem 2. *Let T_2 be the minimum of T_ε^E and T_δ^E. If the difference in profits between leading and being preempted with the disruption for the entrant are greater than the difference between leading and being preempted with the extension for the incumbent, then the unique perfect preemption equilibrium is when the incumbent launches the disruption at T_2.*

An entrant with a capabilities advantage with the extension is unlikely because the entrant is not the current market leader. However, the incumbent may have a capabilities advantage in the disruption, possibly from its continued investments in new technologies. In this case the incumbent would not only have the advantage of the technology with the greater market response, but it would also have a stronger incentive to preempt. Hence, even if the entrant has an advantage with the extension, the incumbent launches the disruption and retains its market leadership.

3.3.3. Summary. We have examined the combinations where firms do or do not have a capabilities advantage, and where one next generation product may or may not have greater market response. Entry is only possible if the entrant has a capabilities advantage. In markets where the next generation products have a significant difference in their market response, the entrant's launch cost advantage resulting from their capabilities advantage with the disruption need only be as large as the incentive to preempt.

If the next generation products do *not* differ in market response, then the entrant must have a dominant capabilities advantage to overcome the incumbent's incentive to preempt as well as the incumbent's capabilities advantage with the extension. We consider this to be unlikely.

4. Loss at the Margin from Launch

In each equilibrium, the launching firm can lose money at the margin on the launch of the next generation product. That is, the launching firm does not cover the costs of its launch from the additional profits generated by the launch. This is strictly the result of competitive pressures to protect or gain market leadership and holds regardless of which firm launches the next generation product—the entrant or the incumbent. In the following theorem we provide the conditions for when a loss at the margin is more likely to occur.

Theorem 3. *A loss at the margin is more likely to occur* (a) *the greater the launch costs associated with the next generation product, and* (b) *the greater the present value of profit flows from the current generation product.*

The next corollary provides a necessary condition for a loss at the margin to occur that rules out special cases where there are positive externalities in profit flows from being a follower. These positive externalities could occur, for example, if the incumbent's launch of the disruption also involves discontinuing its current generation product—leaving the entrant with less competition in the current generation market.

Corollary 1. *A necessary condition for a loss at the margin to occur is that the present value of profit flows from the current generation product are greater than the profit flows from following with the disruption.*

Our finding that it is possible for either the entrant or incumbent to incur a loss at the margin is consistent with what Clemons and Weber (1990) have termed "the vanishing status quo." In many IT and telecommunications industries, there appears to be an unending push towards higher price-performance levels. Associated with these improvements is an increased investment in product launch. The first part of Theorem 3 demonstrates that the likelihood of incurring a loss at the margin increases as the launch costs associated with the next generation product increase. This result is straightforward as profit flows from the next generation product are required to offset these costs. For example, although semiconductor companies agree that because of competition they have to continue to increase the performance of their products to remain viable, payoffs from future microchip projects are questionable because the high fixed costs of R&D and production facilities may limit returns (*Business Week* 1994).

The second part of Theorem 3 suggests that a loss at the margin is more likely to occur the greater the present value of profit flows from the current generation product at the time of the next generation launch. Though a high present value can occur when the current product competes in a large and profitable market, it is likely that the profit flows resulting from the next generation product in this high-demand marketplace will be sufficient to prevent a loss at the margin. However, higher present values of the profit flows for the current product also occur when the next generation product is launched only a short time after the current generation product was launched. In this situation, the additive launch costs need to be recouped by the current and next generation profit flows that, when combined, are not as high as if the products were independent of each other. This finding is important in light of the common belief that product lifecycles are shortening (Dumaine 1989).

5. Discussion

Using a contingency framework, we illustrate how, in equilibrium, an entrant is able to launch the next generation product and assume leadership. The explanation accounts for an incumbent that is fully aware of potential market developments and willing to preempt potential entrants in order to maintain market leadership. Our results highlight the importance of entrants "choosing their spots" when it comes to attempting to enter new markets as, under certain conditions, incumbent preemption is also an equilibrium.

Firms' different resource and capability advantages play an important role in our analysis, for without them the entrant never assumes leadership. The addition of differential market response between the extension and the disruption allows us to define conclusive conditions under which the entrant assumes the leadership role. Entry occurs in spite of an incumbent with a capability advantage with the extension. In fact, entry is possible even if the entrant has a resource or capabilities disadvantage (similar in size to its own advantage) in a next generation product extension.

These results accentuate the importance of a firm understanding where it has resource and capability advantages over its rivals. These advantages can be associated with resources of the firms such as intellectual property or customer access as well as the internal application of processes like environmental scanning, benchmarking, product development, learning, product launch, and marketing. For example, Motorola became a leader in cellular telephones because its wireless capabilities were essential, while AT&T and Nortel, leaders in the production of wired telephone handsets, are still struggling to regain lost ground. In the home PC market, Hewlett Packard went from nowhere to one of the top six in the industry by leveraging its quick product development processes, superior logistics, and strong marketing and launch capabilities (*Business Week* 1996). However, other firms mistakenly assumed a capabilities advantage where there was none. AT&T took a multi-million dollar charge for its failed attempt to get into the PC business after realizing that its telecommunications capabilities did not transfer. IBM had a similar experience, through Rolm, in the telecommunications industry. Even Microsoft, despite considerable development and promotion expenditures, mistakenly assumed that its software capability would enable Microsoft Money to overcome Intuit's Quicken.

Over time, firms need to learn how to capitalize on their relative advantages. We argue that market outcomes may be a good mechanism to allow firms to learn about their resources and capabilities. Failing to maintain a lead may require some investment in building resources and capabilities. In addition, given that there are possible path dependencies that can limit technological opportunities (Teece et al. 1997), losing or failing to gain leadership may require a decision to refine the product-market scope in which the firm competes. Likewise, leading in a generation can provide insight as to the sources of differential advantage over competitors.

Our results underscore the importance of market response in allowing entry. A capabilities advantage in the disruptive technology is a necessary but not sufficient condition for entry. The profit boost afforded by the market response to the disruption makes the entrant launch result conclusive. The growing literature on disruptive technologies (Bower and Christensen 1995), industry breakpoints (Strebel 1995), and technological transitions (Foster 1985) all indicate the need for competitors to recognize when new technological developments can radically alter the feature set of current products. Similarly, firms must detect changes in market trends and consumer preferences in order to identify new and underserviced market segments.

We also show that the leader in the next generation may lose money at the margin on its new product launch. From a social perspective, these characteristics tend to transfer more value to the consumer. For example, a McKinsey study of the PC industry, where inter-generation times are shrinking, found that by 1991, lower prices had allowed PC consumers to capture almost half of the industry profits which were present in 1986 (*Business Week* 1992).

The fact that a preemptive launch and a loss at the margin are best responses points to the need to develop a different model for making internal business case decisions. Typically, a business case requires a positive return based on incremental sales and profits before the project is approved. However, our model suggests that much of the investment may be dedicated to maintaining the status quo. In fact, given that it takes time to develop a new product, firms may need to make technology investment decisions long before the current generation product has reached its profit flow peak. Though companies are realizing that they must invest to protect their market position, more research is needed to provide better guidelines for investment assessment practice. It appears that individual project assessment needs to take place within a broader framework of technology strategy and the metrics used in evaluation must include future-oriented measures such as market position and R&D capability in addition to, or instead of, return on investment and cash flow. To do this effectively, technology roadmaps must be integrated with strong competitive and market intelligence to enable firms to act quickly—both to initiate and to halt technology investments.

Finally, though we believe our model applies to a wide variety of IT and telecommunications products and services, it will be more difficult for the entrant to overcome incumbent advantages due to significant switching costs, network effects, or other externalities. These "extra" advantages are not directly accounted for in our model and under these circumstances firm decisions may differ from those we find. Examples of these situations might include hardware products, where there is a significant investment in proprietary equipment (e.g., early telecom systems), or software products, where there would be a significant amount of re-learning required or there is limited availability of complementary products (e.g., SAP or Microsoft OS). However, as standards evolve, these externalities are being reduced in importance across a variety of industries.

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Mathematical Appendix

Definitions and Assumptions (Not in the text)

Definition 1 (Incentive to Preempt).

$$\int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]\, e^{-rt}\, dt > \int_T^{\bar{T}} [\varepsilon_1^E(t) - \varepsilon_2^E(t)]\, e^{-rt}\, dt$$

and

$$\int_T^{\bar{T}} [\delta_1^I(t) - \delta_2^I(t)]\, e^{-rt}\, dt > \int_T^{\bar{T}} [\delta_1^E(t) - \delta_2^E(t)]\, e^{-rt}\, dt.$$

Definition 2 (Market Response).

$$\int_T^{\bar{T}} \delta_1^i(t) e^{-rt}\, dt > \int_T^{\bar{T}} \varepsilon_1^i(t) e^{-rt}\, dt.$$

Assumption 1.

$$\frac{d[K_j(t)e^{rt}]}{dt} < 0 \text{ and } \frac{d^2[K_j(t)e^{rt}]}{dt^2} > 0 \ \forall\ t < \bar{T},$$

$$\lim_{t\to\bar{T}} \inf K_j(t) = 0, \qquad j \in \{\varepsilon, \delta\}.$$

Assumption 1 implies similar conditions on real costs:

$$\frac{d[K_j(t)e^{rt}]}{dt} = \frac{dK_j(t)}{dt} e^{rt} + K_j(t) r e^{rt} < 0$$

$$\Rightarrow \frac{dK_j(t)}{dt} < -K_j(t) r < 0,$$

and

$$\frac{d^2[K_j(t)e^{rt}]}{dt^2} = \frac{d^2K_j(t)}{dt^2} e^{rt} + 2\frac{dK_j(t)}{dt} r e^{rt} + K_j(t) r^2 e^{rt} > 0$$

$$\Rightarrow \frac{d^2K_j(t)}{dt^2} > -r\frac{dK_j(t)}{dt} > 0.$$

Assumption 2. *Specifically, if i is second to launch product α (where $\alpha = \varepsilon, \delta$), we require*

$$[\alpha_2^i(T^i) - \alpha_3^i(T^i)] e^{-rT^i} - \frac{dK_\alpha(T^i)}{dT^i} > 0 \tag{1}$$

and

$$\int_T^{\bar{T}} [\alpha_2^i(t) - \alpha_3^i(t)] e^{-rt}\, dt + K_\alpha(T) > 0. \tag{2}$$

The launch cost terms in both (1) *and* (2) *are positive. The assumption of Bertrand competition is embedded in the difference between profit flows from following and simultaneous launch—the difference needs to be sufficiently small in absolute value as to not overcome the launch cost terms.*

Assumption 3. *For firm i,*

(a) $$\int_t^{\bar{T}} [\varepsilon_1^i(t) - \varepsilon_2^i(t)] e^{-rt}\, dt < K_\varepsilon(0)$$

and

$$\int_t^{\bar{T}} [\delta_1^i(t) - \delta_2^i(t)] e^{-rt}\, dt < K_\delta(0),$$

$$\text{(b)} \qquad \inf_t\{K_\varepsilon(t)e^{rt}\} < \int_t^{\bar{T}} [\varepsilon_1^i(t) - \varepsilon_2^i(t)]e^{-rt}\,dt$$

and

$$\inf_t\{K_\delta(t)e^{rt}\} < \int_t^{\bar{T}} [\delta_1^i(t) - \delta_2^i(t)]e^{-rt}\,dt.$$

Conditions for Uniqueness

The four conditions required for existence and uniqueness are C1: Neither firm wants to launch either next generation product immediately after the preceding launch; C2: There is a time for each firm when the payoffs to leading are greater than those from following; C3: In the distant future the payoffs to leading and following are equal; C4: For each firm there is a single continuous period when payoffs to leading are greater than those from following. Mathematically these are C1: $L_j^i(0) - F_j^i(0) < 0$ (setting $T = 0$ at the start of the stage), C2: $\exists t$ such that $L_j^i(T) - F_j^i(T) > 0$, C3: $\lim\inf_{T\to\bar{T}} L_j^i(T) - F_j^i(T) = 0$, and C4: $L_j^i(T) - F_j^i(T)$ is strictly quasi-concave. Using notation for the incumbent launching the extension, $L_\varepsilon^I(T) - F_\varepsilon^I(T)$ is

$$\int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]e^{-rt}\,dt - K_\varepsilon(T). \tag{3}$$

For the four cases C1 and C2 are satisfied by Assumption 3. C3 is satisfied from the combination of converging limits of integration and launch costs tending to zero in the limit from Assumption 1. It remains to show C4. Using the notation as above, setting the first derivative to zero yields

$$-[\varepsilon_1^I(T) - \varepsilon_2^I(T)]e^{-rT} - \frac{dK_\varepsilon(T)}{dT} = 0.$$

Quasi-concavity requires that the second derivative is negative, where the first derivative is zero. Differentiating again yields

$$-\left[\frac{d\varepsilon_1^I(T)}{dT} - \frac{d\varepsilon_2^I(T)}{dT}\right]e^{-rT} + r[\varepsilon_1^I(T) - \varepsilon_2^I(T)]$$
$$e^{-rT} - \frac{dK_\varepsilon^2(T)}{[dT]^2} < 0. \tag{4}$$

Assumption 1, along with (3), means that the combination of the last two terms in (4) are negative. $d\varepsilon_1^I(T)/dT$ is positive because profits are sure to increase at the time of launch and $d\varepsilon_2^I(T)/dT$ is nonpositive because profits cannot increase when a competitor launches. The reasoning for the other three cases is identical.

Proof of Lemma 1. Written mathematically, the conditions in the lemma are

$$\text{(a): } K_\delta^I(T) - K_\delta^E(T) > \int_T^{\bar{T}} [[\delta_1^I(t) - \delta_2^I(t)] - [\delta_1^E(t) - \delta_2^E(t)]]\,e^{-rt}\,dt.$$

$$\text{(b): } \int_T^{\bar{T}} [\delta_1^E(t) - \delta_2^E(t)]e^{-rt}\,dt > \int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]\,e^{-rt}\,dt.$$

We prove the lemma in three parts.

(i) $T_\varepsilon^I < T_\varepsilon^E$ requires

$$\int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]\,e^{-rt}\,dt - K_\varepsilon^I(T)$$
$$> \int_T^{\bar{T}} [\varepsilon_1^E(t) - \varepsilon_2^E(t)]\,e^{-rt}\,dt - K_\varepsilon^E(T).$$

The inequality follows directly from our definitions of capabilities advantage and incentive to preempt.

(ii) $T_\delta^E < T_\delta^I$ requires

$$\int_T^{\bar{T}} [\delta_1^E(t) - \delta_2^E(t)]\,e^{-rt}\,dt - K_\delta^E(T)$$
$$> \int_T^{\bar{T}} [\delta_1^I(t) - \delta_2^I(t)]\,e^{-rt}\,dt - K_\delta^I(T).$$

Recognizing that capabilities advantage means $K_\delta^I(t) > K_\delta^E(t)$, and using our definition of the incentive to preempt, rearranging we have the first condition in the lemma.

(iii) $T_\delta^E < T_\varepsilon^I$ requires

$$\int_T^{\bar{T}} [\delta_1^E(t) - \delta_2^E(t)]\,e^{-rt}\,dt - K_\delta^E(T)$$
$$> \int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]\,e^{-rt}\,dt - K_\varepsilon^I(T).$$

Scaling the two launch costs for the next generation product in which each firm has a capabilities advantage to be equal, $K_\delta^E(t) = K_\varepsilon^I(t)$, means the launch costs can be dropped. The remaining inequality is the second condition in the lemma. □

Proof of Lemma 2. The condition in Lemma 2 is condition (b) in Lemma 1. We prove Lemma 2 in three parts.

(i) $T_\delta^I < T_\delta^E$ requires

$$\int_T^{\bar{T}} [\delta_1^I(t) - \delta_2^I(t)\,]e^{-rt}\,dt - K_\delta^I(T)$$
$$> \int_T^{\bar{T}} [\delta_1^E(t) - \delta_2^E(t)]\,e^{-rt}\,dt - K_\delta^E(T).$$

The inequality follows directly from our definitions of capabilities advantage and incentive to preempt.

(ii) $T_\delta^I < T_\varepsilon^I$ requires

$$\int_T^{\bar{T}} [\delta_1^I(t) - \delta_2^I(t)]\,e^{-rt}\,dt - K_\delta^I(T)$$
$$> \int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]\,e^{-rt}\,dt - K_\varepsilon^I(T).$$

Using the condition in the lemma and the incentive to preempt,

$$\int_T^{\bar{T}} [\delta_1^I(t) - \delta_2^I(t)]\,e^{-rt}\,dt > \int_T^{\bar{T}} [\delta_1^E(t) - \delta_2^E(t)]\,e^{-rt}\,dt$$
$$> \int_T^{\bar{T}} [\varepsilon_1^I(t) - \varepsilon_2^I(t)]e^{-rt}\,dt.$$

Scaling the launch costs for the feature in which each firm has a capabilities advantage to be equal means that $K_\delta^I(t) = K_\varepsilon^E(t)$, and therefore $K_\delta^I(t) < K_\varepsilon^I(t)$.

(iii) $T^I_\delta < T^E_\varepsilon$ requires

$$\int_T^{\bar{T}} [\delta^I_1(t) - \delta^I_2(t)]\, e^{-rt}\, dt - K^I_\delta(T) > \int_T^{\bar{T}} [\varepsilon^E_1(t) - \varepsilon^E_2(t)]\, e^{-rt}\, dt - K^E_\varepsilon(T).$$

Again using the condition in the lemma together with the incentive to preempt,

$$\int_T^{\bar{T}} [\delta^I_1(t) - \delta^I_2(t)]\, e^{-rt}\, dt > \int_T^{\bar{T}} [\varepsilon^E_1(t) - \varepsilon^E_2(t)]\, e^{-rt}\, dt.$$

The launch costs are equal as noted above. □

Proof of Equilibria. The proofs of Theorems 1 and 2 are based on the same reasoning. We provide the proof of Theorem 1 below, and the modification for Theorem 2 is obvious. All of the proofs make use of the strategy spaces and payoff functions defined in Fudenberg and Tirole (1985, Section 4.B, pp. 392–393). We change their notation so that superscripts denote firms and the subscript T denotes time. The proof is similar to that in Nault and Vandenbosch (1996).

Definition 4. A simple strategy for firm i in the game starting at T is a pair of real-valued functions (G^i, α^i): $[T, \infty) \times [T, \infty) \to [0,1] \times [0,1]$ satisfying the following.

- (a) G^i is nondecreasing and right-continuous.
- (b) $\alpha^i > 0 \Rightarrow G^i(T) = 1$.
- (c) α^i is right-differentiable.
- (d) *If* $\alpha^i(T) = 0$ and $T = \inf(s \geq T \mid \alpha^i(\cdot) > 0)$, then $\alpha^i(\cdot)$ has a positive right derivative at T.

Let the "first interval of atoms" be represented by

$$\tau^i(T) = \begin{cases} \infty & \text{if } \alpha^i(s) = 0 \ \forall s \geq T, \\ \inf(s \geq T \mid \alpha^i(\cdot) > 0) & \text{otherwise.} \end{cases}$$

$\tau(T) = \min(\tau^I(T), \tau^E(T))$. $\alpha^i(s) = \lim_{\varepsilon \to 0}[G^i(s) - G^i(s - |\xi|)]$. Let $G^{i-}(T)$ be the left limit of $G^i(\cdot)$ at T. The game begins at $T \geq 0$ so set $G^{i-}(T) = 0$. Payoffs are

$$\begin{aligned} &V^i(T, (G^I, \alpha^I), (G^E, \alpha^E)) \\ &= \left[\int_T^{\tau(T)^-} (L(s)(1 - G^j(s))dG^i(s) + F(s)(1 - G^i(s))dG^j(s) \right. \\ &\quad \left. + \ \varepsilon_{s<\tau(T)} a^i(s) a^j(s) M(s)\right] \\ &\quad + (1 - G^{i-}_T(\tau(T)))(1 - G^{i-}_T(\tau(T))) W^i(\tau(T), (G^I, \alpha^I), (G^E, \alpha^E)), \end{aligned}$$

where $W^i(\cdot)$ is defined as follows: If $\tau^j(T) > \tau^i(T)$, then

$$\begin{aligned} W^i(\tau(T), (G^I, \alpha^I), (G^E, \alpha^E)) &= \left[\frac{G^j(\tau) - G^{j-}(\tau)}{1 - G^{j-}(\tau)}\right] \\ [(1 - \alpha^i(\tau))F(\tau) + \alpha^i(\tau)M(\tau)] &+ \left[\frac{1 - G^j(\tau))}{1 - G^{j-}(\tau)}\right] L(\tau). \end{aligned}$$

If $\tau^i(T) > \tau^j(T)$, then

$$\begin{aligned} W^i(\tau(T), (G^I, \alpha^I), (G^E, \alpha^E)) &= \left[\frac{G^i(\tau) - G^{i-}(\tau)}{1 - G^{i-}(\tau)}\right] \\ [(1 - \alpha^j(\tau))L(\tau) + \alpha^j(\tau)M(\tau)] &+ \left[\frac{1 - G^i(\tau)}{1 - G^{i-}(\tau)}\right] F(\tau). \end{aligned}$$

Finally, if $\tau^I(T) = \tau^E(T)$, then $W^i(\tau(T), (G^i,\alpha^I), (G^E,\alpha^E)) =$

$$\begin{cases} M(\tau) & \text{if } \alpha^i(\tau) = \alpha^j(\tau) = 1, \\ \dfrac{\alpha^i(\tau)(1 - \alpha^j(\tau))L(\tau) + \alpha^j(\tau)(1 - \alpha^i(\tau))F(\tau) + \alpha^i(\tau)\alpha^j(\tau)M(\tau)}{\alpha^i(\tau) + \alpha^j(\tau) - \alpha^i(\tau)\alpha^j(\tau)} & \text{if } 2 > \alpha^i(\tau) + \alpha^j(\tau) > 0, \\ \dfrac{\alpha^{i\prime}(\tau)L(\tau) + \alpha^{j\prime}(\tau)F(\tau)}{\alpha^{i\prime}(\tau) + \alpha^{j\prime}}(\tau) & \text{if } \alpha^i(\tau) = \alpha^j(\tau) = 0. \end{cases}$$

Definition 5. A pair of simple strategies (G^I, α^I) and (G^E, α^E) is a Nash equilibrium of the game starting at T (with neither firm having yet launched) if each firm's strategy maximizes its payoff, $V^i(T,\cdot,\cdot)$, with the other firm's strategy held fixed.

Definition 6. A closed-loop strategy for firms is a collection of simple strategies $(G^i_T(\cdot), \alpha^i_T(\cdot))_{T\geq 0}$ for games starting at T satisfying the intertemporal consistency conditions:

- (e) $G^i_T(T + v) = G^i_T(T + u) + (1 - G^i_T(T + u))G^i_{T+u}(T + v)$ for $T \leq u \leq v$.
- (f) $\alpha^i_T(T + v) = \alpha^i_{T+u}(T + v) = \alpha^i(T + v)$ for $T \leq u \leq v$.

Definition 7. A pair of closed-loop strategies $\{(G^I_T(\cdot),\alpha^I_T(\cdot))\}_{T\geq 0}$ and $\{(G^E_T(\cdot),\alpha^E_T(\cdot))\}_{T\geq 0}$ is a perfect equilibrium if for every T the simple strategies $(G^I_T(\cdot),\alpha^I_T(\cdot))$ and $(G^E_T(\cdot),\alpha^E_T(\cdot))$ are a Nash equilibrium.

Let $\eta^i(T) = \inf\{s \geq T \mid G^i_s(s) > 0\}$. Note that if $\eta^i(0) < \tau^i(0)$, then $\eta^i(0)$ is the first time of an isolated jump. And let $\eta(0) = \min\{\eta^I(0),\eta^E(0)\}$.

Proof of Theorem 1. We examine the case when $T^I_\varepsilon < T^I_\delta$. The alternative cases follow directly. Let $G^E_T(s)$ be the cumulative probability that the entrant has launched the disruption by time s, in the game starting at T, conditional on no launch having yet occurred. Let $G^I_T(s)$ be similarly defined for the incumbent with the extension. $\alpha^i(T)$ measures the intensity of G in $[T,T + dT]$. We propose that the following simple strategies represent the equilibrium.

$$G^E_T(s) = \begin{cases} 0 & \text{if } s < T^I_\varepsilon \\ 1 & \text{if } s \geq T^I_\varepsilon \end{cases}$$

$$\alpha^E(s) = \begin{cases} 0 & \text{if } s < T^I_\varepsilon \\ \dfrac{L^I_\varepsilon(T) - F^I_\varepsilon(T)}{L^I_\varepsilon(T) - M^I_\varepsilon(T)} & \text{if } s \geq T^I_\varepsilon \end{cases}$$

$$G^I_t(s) = \begin{cases} 0 & \text{if } s \leq T^I_\varepsilon \\ 1 & \text{if } s > T^I_\varepsilon \end{cases}$$

$$\alpha^I(s) = \begin{cases} 0 & \text{if } s \leq T^I_\varepsilon \\ \dfrac{L^E_\delta(T) - F^E_\delta(T)}{L^E_\delta(T) - M^E_\delta(T)} & \text{if } s > T^I_\varepsilon \end{cases}$$

We examine games starting at T, $G^{i-}_T(T) = 0$, and strategies for $T \in [T^I_\varepsilon,\bar{T})$. Prior to T^I_ε, waiting is a dominant for both firms.

Working backwards for the entrant, assume that $T \in (T^I_\varepsilon,\bar{T})$. From the incumbent's equilibrium strategy $\alpha^I(T)$, $\tau = \tau^I(T) = T$. If $G_T^E(T) = 0$, then the payoff is $F_\delta^E(T)$. If $G_T^E(T) = \lambda$, $0 < \lambda < 1$, then $\alpha^E(T) = 0$ and $\tau^E(T) > \tau^I(T)$. The payoff defined by $W^E(\cdot)$ is $F_\delta^E(T)$. If $G_T^E(T) = 1$, then $\alpha^E(T) > 0$ and $\tau^E(T) = \tau^I(T)$. With $2 > \alpha^E(T) + \alpha^I(T) > 0$, the payoff $W^E(\cdot)$, after considerable manipulation, is also $F_\delta^E(T)$. Thus, the entrant is indifferent between those strategies over $T \in (T_\varepsilon^I, \bar{T})$.

If $T = T_\varepsilon^I$, then from the incumbent's equilibrium strategy, $\alpha^I(T) = 0$ and $G_T^I(T) = 0$. If $G_T^E(T) = 0$, then $\alpha^E(T) = 0$. Thus, $\tau^E(T) \geq \tau^I(T) = \tau > T_\varepsilon^I$, and $2 > \alpha^E(\tau) + \alpha^I(\tau) > 0$. The payoff is $W^E(\cdot)$, and thus is $F_\delta^E(\tau)$. If $G_T^E(T) = \lambda$, $0 < \lambda \leq 1$, then the situation is the same as when $G_T^E(T) = 0$, so the payoff is also $F_\delta^E(\tau)$. If $G_T^E(T) = 1$, then $\alpha^E(T) > 0$, and $\tau = T_\varepsilon^I = \tau^E(T) < \tau^I(T)$. The remaining terms in $W^E(\cdot)$ cancel and the payoff is $L_\delta^E(\tau)$. Because $L_\delta^E(\tau) > F_\delta^E(\tau)$ when $\tau = T_\varepsilon^I$, the entrant strictly prefers $G_T^E(T) = 1$.

For the incumbent, examine first $T \in (T_\varepsilon^I, \bar{T})$. From the entrant's equilibrium strategy, $\alpha^E(T) > 0$, thus, $\tau^E(T) = \tau(T) = T$. If $G_T^I(T) = 0$, then $\alpha^I(T) = 0$, and $\tau^I(T) > \tau^E(T)$. With the remaining terms dropping out, the payoff is $F_\varepsilon^I(T)$. If $G_T^I(T) = \lambda$, $0 < \lambda \leq 1$, then again $\alpha^I(T) = 0$, and $\tau^I(T) > \tau^E(T)$. Similar to the case of the entrant, $W^I(\cdot) = F_\varepsilon^I(T)$. If $G_T^I(T) = 1$, then $\alpha^I(T) > 0$, $\tau^I(T) = \tau^E(T)$, and $2 > \alpha^E(T) + \alpha^I(T) > 0$. Again as with the entrant, $W^I(\cdot) = F_\varepsilon^I(T)$. Consequently, the incumbent is indifferent over those strategies for $T \in (T_\varepsilon^I, \bar{T})$.

At $T = T_\varepsilon^I$, from the entrant's equilibrium strategy, $\alpha^E(T) > 0$, $G_T^E(T) = 1$, and $\tau = T_\varepsilon^I$. If $G_T^I(T) = 0$, then $\alpha^I(T) = 0$, $\tau^I(T) > \tau^E(T)$. If $G_T^I(T) = \lambda$, $0 < \lambda \leq 1$, then again $\alpha^I(T) = 0$, and $\tau^I(T) > \tau^E(T)$. If $G_T^I(T) = 1$, then $\alpha^I(T) > 0$, $\tau^I(T) = \tau^E(T) = \tau$, and $2 > \alpha^E(\tau) + \alpha^I(\tau) > 0$. Each payoff is the same as when $T \in (T_\varepsilon^I, \bar{T})$, $F_\varepsilon^I(T)$. Hence, the incumbent is also indifferent over those strategies.

These simple strategies are a Nash equilibrium for every T, and are intertemporally consistent over T. As a result they are a perfect equilibrium.

There are no other perfect equilibria. Assume first $\tau(0) \leq \eta(0)$. Before T_δ^E the firms wait because following is more profitable than leading (observing that we ruled out simultaneous launch). Before T_ε^I the incumbent waits because $F_\varepsilon^I(T) > L_\varepsilon^I(T)$. For $T \in [T_\delta^E, T_\varepsilon^I)$ the entrant waits because $L_\delta^E(T + \xi) > L_\delta^E(T)$ for the extension but positive ξ. At any $T \in (T_\varepsilon^I, T)$ each firm's best response is to launch at $\tau(T) - \xi$ because leading at that time is strictly more profitable than following at T. When $T = T_\varepsilon^I$ the entrant launches because $L_\delta^E(T) > F_\delta^E(T)$. By definition of T_ε^I, the incumbent is indifferent between following and leading at that time and therefore is better off not launching at T_ε^I.

Suppose $\eta(0) < \tau(0)$. Before T_δ^E waiting is optimal for both firms. For $T \in [T_\delta^E, T_\varepsilon^I)$, $\eta(T) = \eta^E(T)$ because the incumbent is still better off waiting. But $L_\delta^E(T)$ is increasing in this interval so waiting is also optimal for the entrant. At $T = T_\varepsilon^I$, if $\eta(T) = \eta^E(T)$, then the incumbent can avoid a simultaneous launch by waiting. For $T \in (T_\varepsilon^I, \bar{T})$, if $\eta(T) = \eta^i(T)$, then firm j is better off launching with probability one at $T - \xi$. Finally, at T_ε^I the entrant can avoid a positive probability of a later simultaneous launch by launching with probability one. □

Proof of Theorem 2. Using our definitions and the scaling of launch costs, $L_\delta^I(T_2) > L_\varepsilon^I(T_2)$. Therefore, the incumbent always prefers to launch the disruption. The proof is identical to that of Theorem 1 except that it uses the ordering of critical times in Lemma 2 rather than in Lemma 1. □

Proof of Theorem 3. We prove the theorem for the equilibria from both Theorem 1 and 2. (i) Equilibrium from Theorem 1: Let $\delta_{new}(t)$ be the profit flows solely from the new launch. For the entrant this is $\delta_{new}(t) = \delta_1^E(t) - \pi_2(t)$, or $\delta_1^E(t) = \delta_{new}(t) + \pi_2(t)$. Let T be the time of launch so that $T = \min\{T_\delta^I, T_\varepsilon^I\}$. At T the entrant prefers to lead so

$$\int_T^{\bar{T}} [\delta_{new}(t) + \pi_2(t)]e^{-rt}dt - K_\delta^E(T) > \int_T^{\bar{T}} \delta_2^E(t)e^{-rt}dt > 0.$$

A loss at the margin means

$$\int_T^{\bar{T}} \delta_{new}(t)e^{-rt}dt < K_\delta^E(T). \tag{5}$$

(a) follows directly. To prove (b), if $T = T_\delta^I$, then by definition of the critical time $\int_T^{\bar{T}}[\delta_1^I(t) - \delta_2^I(t)]e^{-rt}dt = K_\delta^I(T)$. Then

$$\int_T^{\bar{T}} [[\delta_1^E(t) - \pi_2(t)] - [\delta_1^I(t) - \delta_2^I(t)]]e^{-rt}dt < K_\delta^E(T) - K_\delta^I(T),$$

where the left hand side is decreasing in $\pi_2(t)$. Otherwise, if $T = T_\varepsilon^I$, then by definition of the critical time $\int_T^{\bar{T}}[\varepsilon_1^I(t) - \varepsilon_2^I(t)]e^{-rt}dt = K_\varepsilon^I(T)$. The remaining reasoning is the same as for $T = T_\delta^I$. (ii) Equilibrium from Theorem 2: For the incumbent $\delta_{new}(t) = \delta_1^I(t) - \pi_1(t)$, or $\delta_1^I(t) = \delta_{new}(t) + \pi_1(t)$. $T = \min\{T_\delta^E, T_\varepsilon^E\}$. At T the incumbent prefers to lead so

$$\int_T^{\bar{T}} [\delta_{new}(t) + \pi_1(t)]e^{-rt}dt - K_\delta^I(T) > \int_T^{\bar{T}} \delta_2^I(t)e^{-rt}dt > 0.$$

and a loss at the margin means $\int_T^{\bar{T}} \delta_{new}(t)e^{-rt}dt < K_\delta^I(T)$. If $T = T_\delta^I$, then using the same reasoning as (i) above

$$\int_T^{\bar{T}} [[\delta_1^I(t) - \pi_1(t)] - [\delta_1^E(t) - \delta_2^E(t)]]e^{-rt}dt < K_\delta^I(T) - K_\delta^E(T),$$

where the left hand side is decreasing in $\pi_1(t)$. The case when $T = T_\varepsilon^E$ also follows as in (i). □

Proof of Corollary. In the case of the entrant (5) implies $\int_T^{\bar{T}}[\pi_2(t) - \delta_2^E]e^{-rt}dt > 0$. For the incumbent the argument is identical. □

References

Amit, R., P. Schoemaker. 1993. Strategic assets and organizational rent. *Strategic Management J.* **14**(1) 33–46.

Barney, J. 1991. Firm resources and sustained competitive advantage. *J. Management* **17**(1) 99–120.

Bower, J. L., C. M. Christensen. 1995. Disruptive technologies: Catching the wave. *Harvard Bus. Rev.* **73**(1) 43–53.

Business Week. 1992. Deconstructing the computer industry. (November 23) 90–100.

——. 1994. Will we keep getting more bits for the buck? (July 4) 90–91.

——. 1996. Suddenly, it's "price, price, price". (June 17) 134–135.

Clemons, E. K., B. W. Weber. 1990. Strategic information technology investments: Guidelines for decision making. *J. Management Inform. Systems* **7**(2) 9–28.

D'Aveni, R. A. 1994. *Hypercompetition.* Free Press, New York.

Deutschman, A. 1994. The managing wisdom of high-tech superstars. *Fortune* (October 17) 197–206.

Dierickx, I., K. Cool. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Sci.* **35**(12) 1504–1511.

Dixit, A. 1979. A model of duopoly suggesting a theory of entry barriers. *Bell J. Econom.* **10**(1) 20–32.

——. 1980. The role of investment in entry-deterrence. *Econom. J.* **90** (March) 95–108.

Dumaine, B. 1989. How managers succeed through speed. *Fortune* (February 13) 54–59.

Eaton, B. C., R. G. Lipsey. 1980. Exit barriers are entry barriers: The durability of capital as a barrier to entry. *Bell J. Econom.* **11**(2) 721–729.

Foster, R. N. 1985. Timing technological transitions. *Tech. Soc.* **7** 127–141.

Fudenberg, D., J. Tirole. 1983. Capital as a commitment: Strategic investment to deter mobility. *J. Econom. Theory* **31** 227–250.

——, ——. 1985. Preemption and rent equalization in the adoption of new technology. *Rev. Econom. Stud.* **52** (June) 383–401.

Gaynor, G. 1993. *Exploiting Cycle Time in Technology Management.* McGraw-Hill, New York.

Ghemawat, P. 1991. Market incumbency and technological inertia. *Marketing Sci.* **10**(2) 161–171.

Gomes, L. 1996. Cyrix Corp. follows AMD in predicting losses for quarter. *Wall Street Journal* (June 24).

Grant, R. M. 1991. The resource-based theory of competitive advantage: Implications for strategy formulation. *California Management Rev.* **33**(3) 114–135.

——. 1995. *Contemporary Strategic Analysis*, 2nd Ed. Blackwell Publishers Inc., Cambridge, MA.

Harvard Business School. 1990. AUCNET: TV auction network system. Harvard Business School, 9-9-190- 001.

Judd, K. 1985. Credible spatial preemption. *Rand J. Econom.* **16**(1) 153–166.

Kamien, M. I., N. L. Schwartz. 1982. *Market Structure and Innovation.* Cambridge University Press, Cambridge, MA.

Katz, M. L., C. Shapiro. 1987. R&D rivalry with licensing or imitation. *Amer. Econom. Rev.* **75** 429–436.

Klepper, S. 1996. Entry, exit, growth, and innovation over the product life cycle. *Amer. Econom. Rev.* **86**(3) 562–583.

Lieberman, M. B., D. B. Montgomery. 1998. First-mover (dis)advantages: Retrospective and link with the resource-based view. *Strategic Management J.* **19**(12) 1111–1125.

Lippman, S. A., R. P. Rumelt. 1982. Uncertain imitability: An analysis of interfirm differences in efficiency under competition. *Bell J. Econom.* **13**(2) 418–438.

Nault, B. R., M. B. Vandenbosch. 1996. Eating your own lunch: Protection through preemption. *Organ. Sci.* **7**(3) 342–358.

Patterson, M. 1993. *Accelerating Innovation.* VanNostrand Reinhold, New York.

Prahalad, C. K., G. Hamel. 1990. The core competence of the corporation. *Harvard Bus. Rev.* (May–June) 79–91.

Reinganum, J. F. 1981. On the diffusion of new technology: A game theoretic approach. *Rev. Econom. Stud.* **153** 395–406.

——. 1983. Uncertain innovation and the persistence of monopoly. *Amer. Econom. Rev.* **73**(4) 741–748.

——. 1985. Innovation and industry evolution. *Quart. J. Econom.* **100** (February) 81–99.

Schoenecker, T. S., A. C. Cooper. 1998. The role of firm resources and organizational attributes in determining entry timing: A cross-industry study. *Strategic Management J.* **19**(12) 1127–1143.

Spence, A. M. 1977. Entry, capacity, investment and oligopolistic pricing. *Bell J. Econom.* **8**(2) 534–544.

——. 1979. Investment strategy and growth in a new market. *Bell J. Econom.* **10**(1) 1–19.

Strebel, P. 1995. Creating industry breakpoints: Changing the rules of the game. *Long Range Planning* **28** (April) 11–20.

Teece, D., G. Pisano, A. Shuen. 1977. Dynamic capabilities and strategic management. *Strategic Management J.* **18**(7) 509–533.

Tirole, J. 1988. *The Theory of Industrial Organization.* MIT Press, Cambridge, MA.

Utterback, J. M. 1995. Developing technologies: The Eastman Kodak story. *McKinsey Quart.* **1** 130–143.

Vandenbosch, M. B., C. B. Weinberg. 1995. Product and price competition in a two-dimensional vertical differentiation model. *Marketing Sci.* **14**(2) 224–249.

Wernerfelt, B. 1984. A resource-based view of the firm. *Strategic Management J.* **5** 171–180.

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