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Market Research and Innovation Strategy in a Duopoly

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We model a duopoly in which ex ante identical firms must decide where to direct their innovation efforts. The firms face market uncertainty about consumers' preferences for innovation on two product attributes and technology uncertainty about the success of their research and development (R&D) investments. Firms can conduct costly market research before setting R&D strategy. We find that the value of market information to a firm depends on whether its rival is expected to obtain this information in equilibrium. Consequently, one firm may forgo market research even though its rival conducts such research and learns the true state of demand. We examine both vertical and horizontal demand structures. With vertical preferences, firms are a priori uncertain about which attribute all consumers will value more. In this case, a firm that conducts market research always attempts innovation on the attribute it discovers that consumers prefer and expends more on R&D than a rival that has not conducted market research. With horizontal preferences, distinct segments exist—each caring about innovation on only one attribute—and firms are a priori uncertain how many consumers each segment contains. In this case, a firm that conducts market research may follow a *niche* strategy and attempt innovation to serve the smaller segment to avoid intense price competition for the larger segment. A firm that conducts market research may therefore invest less in R&D and earn lower postlaunch profits than a rival that has forgone such research.

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1. Introduction

New product strategy often boils down to determining what novel feature to develop or which attribute to significantly improve. In deciding where to direct research and development (R&D) effort, firms face uncertainty not only with respect to the technical feasibility of each innovation considered but also with respect to market demand for it. Market uncertainty arises because firms may not know a priori how much or how many consumers would value a planned new feature or a proposed attribute improvement.

Consider the following examples. In the mid-1990s, Compaq and Toshiba faced a dilemma in the development of laptops for the consumer market. Because this market was still emerging and consumer preferences for various concepts were unclear, the dilemma was whether to focus on reducing weight by allowing only light and interchangeable peripherals (the CD-ROM and floppy drive would be modular and could not be used simultaneously) or to focus on offering greater convenience by attempting

to integrate all the peripherals internally and including high-performance components that further added weight (Bell and Leamon 1999). In the mid-1980s, firms in the disk drive industry, such as Seagate and Conner Peripherals, were not sure if the market would shift to smaller drives and contemplated whether to dedicate R&D effort to reducing drive size or to increasing memory capacity (Christensen 1997). In the early 2000s, firms in the cell phone handset market (Nokia and Motorola) were not sure about consumers' tastes for different designs and faced a choice between investing in the candy bar or clamshell styles (*The Economist* 2004). Pharmaceutical firms (e.g., Eli Lilly, Pfizer, Forest) were uncertain about demand for new antidepressants and had to decide whether to develop a drug with better efficacy in treating acute depression or a drug that would cotreat physical pain symptoms associated with mild depression (Ofek 2006).

Interestingly, in several of these examples firms in the same industry pursued different product development paths (that is, they chose to improve differ-

ent attributes, incorporate different new features, or focus on distinct designs), while in other cases all firms chose the same development path. Moreover, substantial research to resolve the market uncertainty and guide development was sometimes, but not always, conducted. In the laptop example given above, Compaq conducted extensive market research (in the form of numerous focus group testings) prior to development. Among cell phone firms, Nokia continued to develop new candy bar handsets without conducting extensive upfront market research.[1] Hence, there seems to be variance in firms' strategies with respect to conducting market research, the choice of which innovation path to pursue, or both.

In this paper, we shed light on how firms make such innovation-related decisions and explore the implications of market research in a strategic setting. Using a game-theoretic model, we study a duopoly with identical firms that need to decide which of two product attributes to attempt innovation on. Firms face market uncertainty with only a prior probability distribution about consumer preferences. Our analysis addresses the following research questions.

• Given ex ante identical firms, should we always expect symmetric equilibria in the decision to conduct market research? Can it be optimal for one firm to forgo market research while its rival conducts such research?

• Under what conditions do firms attempt innovation on the same versus different attributes? Will a firm that conducts market research always choose the attribute that yields greater demand?

• What is the relationship between conducting market research and the R&D level a firm selects? When does market research induce a greater R&D level? When does it induce a lower R&D level?

In addressing these questions, we distinguish between two types of uncertainty about consumer preferences for new products. In the first, which we call *vertical*, all consumers value innovation on both attributes but prefer one over the other. Firms are initially uncertain which innovation customers will value more, although they may have a prior belief that one attribute is more likely to be preferred. In the disk drive example (Christensen 1997), firms were unsure if

smaller drives, which were more rugged and could be used in smaller machines, would actually be more relevant for end users and become the standard; the prevailing prior was that capacity improvement was more important. In the laptop example, Compaq originally conjectured that consumers would be averse to heavy machines and highly value the concept of lightweight modularity (Bell and Leamon 1999).

To model such vertical market uncertainty, we assume that firms assign a probability that each attribute is the one more valued by consumers. The attribute with a higher ex ante likelihood of being preferred is called the *safer* attribute. Our analysis reveals two countervailing incentives for firms to undertake upfront market research. On the one hand, there is a direct benefit because conducting market research allows a firm to foresee the attribute most valued by consumers. On the other hand, if both firms conduct market research there is a correlating competitive drawback. Specifically, when both firms discover which attribute consumers prefer, they will attempt innovation on the same attribute and compete head-to-head. Therefore, the value to a firm of information from market research depends on whether its rival also has this information. These considerations give rise to three primary equilibria depending on the cost (or difficulty) of conducting market research: (1) Both firms conduct market research and innovate on the attribute discovered to be preferred by consumers; (2) only one firm conducts market research, and its rival that forgoes market research pursues the safer attribute; and (3) neither firm conducts market research, and both innovate on the safe attribute or each firm selects a different attribute to innovate on. Thus, an asymmetric equilibrium in terms of how informed each firm is about the demand can arise endogenously even though the two firms are initially identical in every respect. The firm that conducts market research pursues the most valued attribute and hence can never be worse off in terms of postlaunch profits than the firm that forgoes market research if both introduce new products. The analysis further shows that in case (3), when both firms forgo market research, the decision on which attribute to innovate on is driven by two factors. The first reflects a desire to avoid market uncertainty as much as possible and drives both firms to select the attribute perceived to be safer ex ante. The second reflects a desire to soften future competition and drives firms to differentiate by selecting separate attributes to innovate on, with each firm gambling that it has chosen the preferred attribute. This differentiation force dominates when technical uncertainty is relatively low; i.e., firms are likely to succeed in their product development efforts. Thus, when neither firm conducts market research we can expect more divergence in the innovation paths

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[1] Consumers in Compaq's market research did not respond favorably to the concept of interchangeability to reduce laptop weight, but wanted the convenience of all add-ons integrated internally and better performance. This information led to the development of the Presario notebook line, which garnered dominant market share shortly after being introduced in 1996. In Nokia's case, it bet on developing the wrong handset style and lost a significant share in 2004 to Motorola, which introduced clamshell phones. In the antidepressant case, market research by Lilly revealed that roughly 25% of mildly depressed patients suffered from physical pain (Ofek 2006); Lilly, indeed, pursued a Food and Drug Administration indication for pain in addition to an indication for treating depression.

selected relative to when both firms conduct market research.

Market research also has implications for firms' R&D levels. An informed firm facing an uninformed rival is induced to select the highest R&D level because it knows through market research that it is pursuing the most valued attribute and hence that its expected rewards are higher. The uninformed rival responds by selecting a relatively low R&D level because of strategic substitutability. As such, within the vertical preference structure, a predisposition to be market oriented with respect to innovation causes the firm to expend more on R&D compared to a rival that is not market oriented.

In the second type of consumer preference structure, which we call *horizontal*, there are two distinct segments and each values innovation on only one of the attributes. Firms are initially uncertain as to the size of these segments. In the pharmaceutical example given earlier, there was anecdotal evidence that some patients had mild depression symptoms yet suffered considerably from related physical pain, vis-à-vis other patients (classified as hard to treat) for whom existing drugs were relatively ineffective in treating their depression, but who had no associated pain. An innovative drug that alleviated comorbid pain while offering comparable efficacy to existing drugs in treating depression would appeal only to the former segment, whereas a new drug that offered greater efficacy in treating acute depression would mainly appeal to the latter segment. However, it was not clear ex ante how big these segments were.

To model such horizontal market uncertainty, the size of the segments is assumed to be a random variable that can take on any value between zero and one. The two segments are of ex ante equal expected size; a firm that conducts market research learns the true size of the segments. In this case, we find that market research can have the property of *negatively correlating* firms' innovation paths. Specifically, a firm that conducts market research may target the smaller niche segment with its innovative efforts as a way to secure some profits and avoid harsh price competition for the larger segment. This result holds in an asymmetric equilibrium, where a single firm conducts market research, as well as for one of the firms in an equilibrium where both conduct market research. When a firm knowingly attempts innovation for the niche segment, it tends to select a relatively low R&D level and will earn lower postlaunch profits than its rival if both manage to develop new products. This type of segmented equilibrium is more prevalent the lower the technical uncertainty because when development effort is likely to succeed, the need to differentiate is more pronounced.

In both the vertical and horizontal cases, equilibria exist where ex ante identical firms behave asymmetrically in the decision to conduct market research. This asymmetry results in firms having different knowledge of the true state of demand when setting subsequent innovation strategy. In the vertical case the informed firm always pursues the attribute discovered to be preferred by consumers. In the horizontal case, however, the informed firm might use this knowledge to opt for the attribute valued by fewer consumers, if doing so makes more sense than the risk of fierce rivalry entailed by innovation for the larger segment.

In terms of prior related work, limited analytic research has examined firms' incentives to choose among different innovation paths. Jovanovic and Rob (1987) assume uncertain demand and let firms gather market information before selecting a new product location. However, in their model, firms face no technology development hurdle and do not compete with their new products (they act as price takers). Cabral (2002, 2003) show that an initial asymmetry in industry position (technology gap between a leader and a follower) results in an asymmetry in the technology path each firm pursues. In both these papers, R&D budgets are fixed, and the rewards to each path are known ex ante. By contrast, firms in our model are in the same industry position at the outset, R&D budgets are endogenously determined, and, importantly, firms are uncertain about the payoffs that will result from each path. In marketing, Iyer and Soberman (2000) study competing firms' incentives to purchase information relevant for product modifications from a strategic vendor. In their model, firms do not make decisions under demand uncertainty, and acquiring the information automatically enables offering the modified product (i.e., no product development is undertaken). Luo et al. (2007) analyze how a manufacturer selects which new product to introduce in the presence of a dominant retailer. Their focus is new product positioning and pricing to effect support by the main retailer, yet they do not account for demand or technological uncertainty for new products. Ofek and Turut (2008) examine the incentives to conduct market research when an entrant must decide between innovation and imitation. They focus mainly on the signaling properties of product development and characterize when an incumbent can forgo market research by drawing inferences from a me-too versus innovative entry strategy. By contrast, we examine identical firms that face uncertainty about consumer preferences for innovation on two separate attributes. In our model, signaling considerations do not arise, and a firm's decision to forgo market research is linked to a decrease in the value of information when a rival conducts such research. Because we micromodel

two types of demand structures (vertical and horizontal), our analysis yields implications for various forms of market research in the new product development (NPD) context. Ofek and Turut (2008), however, use only reduced form profits, and market research is not relevant for deciding between different innovation paths. Our findings in this regard constitute a central contribution to existing research.

The extant literature thus largely ignores the confluence of demand and technology uncertainties as they pertain to the choice of which innovation path to pursue and does not examine the incentives to reduce those uncertainties within a unified framework. This is despite evidence of the dual source of uncertainty competing firms face in NPD (Cooper and Kleinschmidt 1987).[2] Moreover, marketers stress the need to incorporate input on consumer desires prior to R&D effort (Griffin and Hauser 1993)—in the form of conjoint analysis, concept testing, etc. Rather, marketers keep offering new techniques and managerially effective methods to achieve this (e.g., Toubia et al. 2003, Toubia and Hauser 2007). However, the strategic consequences of a customer-centric orientation to innovation when a competitor is (or is not) embracing such an orientation are not well understood.

Finally, prior work has also examined strategic information acquisition that aids in subsequent pricing or quantity decisions. For example, the incentives to resolve demand uncertainty have been studied by Li et al. (1987) with quantity competition and by Raju and Roy (2000) with price competition. In our model, market research sheds substantive light on the potential rewards of various innovation paths and the return on risky R&D investment, thereby introducing different considerations relative to the literature.

The rest of the paper is organized as follows. Section 2 describes the model setup. Sections 3 and 4 investigate firms' innovation strategies when confronted with vertical and horizontal market uncertainties, respectively. In §5, extensions and limitations of the analysis are discussed. Section 6 summarizes key findings and managerial implications.

2. Model Setup

Two identical firms, indexed $i \in (1, 2)$, are planning to introduce a new product into a given market in the next period. They face a decision about the direction of their innovative efforts. In particular, there are two attributes or features, indexed $j \in (a, b)$. Each firm has to decide to which of these attributes it will devote R&D investment. This characteristic of our model captures the undesirability of pursuing (or the

inability to pursue) numerous innovation paths in a given time frame and, therefore, the need to select among them.[3]

For a given innovation path chosen, the R&D intensity a firm selects affects the probability that development effort will succeed. The more a firm wishes to ensure product development success, the more costly it is at an increasing marginal rate. We use a quadratic cost function to capture this. When a firm attempts innovation on attribute j, the R&D success probability it selects will be denoted φ_j and it incurs a cost of $\frac{1}{2}K\varphi_j^2$, where $\varphi_j \in [0, 1)$ and K is the development cost factor. From a technology development standpoint, the two attributes are equivalent in the sense that the likelihood of R&D success is the same for a given expenditure. If firm i's R&D efforts succeed, it introduces a new product and prices it at $p(i) \geq 0$. If both firms introduce new products, Bertrand price competition (Tirole 1988) ensues. Consumers buy at most one good and maximize their utility conditional on the new products offered and on prices. If a product with no innovation on either attribute is offered, we assume that it is identical to existing products and thus yields zero profits.[4] In §5, we discuss the impact on our findings of extending the model to allow firms to determine the degree of innovation on each attribute (*radical* or *incremental*) or to pursue multiple innovations.

Beyond the technology development uncertainty, there is also ex ante uncertainty about consumer preferences. We examine two forms of market uncertainty. In the first, all consumers value innovation on both attributes, but firms are ex ante uncertain as to which attribute consumers value more. We call this demand structure vertical. In the second, a segment of consumers only desire innovation on attribute a and the other segment only on attribute b, but firms are

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[2] Reviewing a number of studies, they report that on average 46% of R&D projects fail to result in a working product and 35% of new products successfully developed fail to gain consumer acceptance.

[3] This assumption is realistic as in many cases trying to pursue multiple paths diverts management attention or requires significant set-up costs for each path so that a firm would not find it optimal do so (see Thomke and Krishnan 1999 for an example). Furthermore, there are typically diseconomies of scope in simultaneously improving multiple attributes (*The Economist* 2002). The examples given in §1 and the Industrial Organization (IO) literature cited earlier (Jovanovic and Rob 1987; Cabral 2002, 2003) are consistent with this characterization.

[4] Specifically, we assume that both firms can offer existing products with no innovation such that Bertrand price competition drives their prices to zero (or that by the next period other suppliers will enter and commoditize these products). We further assume that consumers derive additional utility from innovative products. Mathematically, let existing products yield consumers utility of v_0 and let an innovation increase this base utility by v_{inn} and be priced at p ($p \leq v_{inn}$). Then in comparing the utility from the existing product to that of an innovative product, v_0 cancels out. Thus, our normalization of $v_0 \equiv 0$ is without loss of generality. For pricing issues that can arise between successive new product generations, see Sankaranayanan (2007).

ex ante uncertain about the size of these segments. We call this demand structure horizontal. Our designation of these demand structures as vertical and horizontal is consistent with standard definitions in the IO and marketing literatures on product differentiation.[5]

Given the uncertainty about consumer preferences, firms may wish to conduct upfront market research to guide their innovation decisions. Market research comes at a cost of $C \geq 0$, and for simplicity we assume it perfectly resolves the demand uncertainty. If a firm conducts market research we will say the firm is informed and denote this by $mr = 1$. If a firm forgoes such research we will say the firm is uninformed and denote this by $mr = 0$. When a firm conducts market research it learns which attribute is preferred, i.e., more valued by consumers in the vertical case or valued by the larger segment of consumers in the horizontal case. If an informed firm attempts innovation on the preferred attribute, we denote this choice by c, and if it attempts innovation on the less preferred attribute we denote by $\bar{c}$ $(c, \bar{c} \in \{a, b\})$. This notation allows us to refer to the strategy of an informed firm in terms of how the attribute it chooses depends on the results of market research.

The timing of the game is as follows. In the first stage $(t = 1)$ firms simultaneously set their NPD strategy: they decide whether to commission market research (mr), choose which attribute to attempt innovation on (j), and select their R&D intensity (φ_j). In the second stage $(t = 2)$, firms' development efforts conclude and they set prices (p) for their new products. Note that if a firm conducts market research it resolves demand uncertainty at $t = 1$, but if it forgoes market research, it learns the realization of demand only at $t = 2$. We discuss variations to this timeline and the possibility that market research is time consuming in §5. An example of a possible strategy vector for firm i is as follows:

1. Conduct market research $(mr = 1)$, attempt innovation on the attribute discovered to be preferred c, and select R&D level φ_c;

2. When R&D efforts are successful:

—if the competitor failed, charge price p_c^m (price a monopolist would charge having innovated on the preferred attribute);

—if the competitor succeeded, charge price p_c^d (duopoly price depending on rival's new product).

Firms are risk neutral and maximize expected payoffs. We denote by $\pi_j(i)$ firm i's profits when it has chosen attribute j and assume for simplicity that variable production costs are zero. The game is solved through backward induction starting with the pricing subgame at $t = 2$. All proofs are provided in the appendix.

3. Vertical Preferences over the Attribute Space

In this section, we study the case in which all consumers have similar preferences over the product attribute space and place positive value on both attributes. But ex ante firms do not know if they would prefer to adopt a new product that offers innovation on attribute a or b. To capture this type of market uncertainty, we assume that with probability $0 < \alpha < \frac{1}{2}$ consumers prefer innovation on attribute a, and with probability $1 - \alpha > \frac{1}{2}$ they prefer innovation on attribute b.[6] Thus, without loss of generality, b is the safer attribute. This captures the fact that in practice firms often have an a priori belief that certain attributes are more likely to matter to consumers than others (the limiting case of $\alpha = \frac{1}{2}$ is studied in §3.1.3). When a firm successfully innovates on the attribute or feature that is more valued, consumers derive utility V from the new product. When a firm successfully innovates on the attribute that is less valued, consumers derive utility $V - D$ from the new product, where $D \in (0, V)$ captures the degree of consumer disutility. Hence, a new product with innovation on attribute a will be vertically differentiated from a new product with innovation on attribute b.[7] To summarize, the utility a consumer derives from purchasing a new product from firm i, conditional on the success of its R&D efforts, is given by

$$u(i) = V - I(i) \cdot D - p(i), \text{ where}$$

$$I(i) = \begin{cases} 0 & \text{if firm } i \text{ innovates on the attribute} \\ & \text{more valued by consumers,} \\ 1 & \text{if firm } i \text{ innovates on the attribute} \\ & \text{less valued by consumers.} \end{cases}$$

The following lemma characterizes the outcome of the final subgame depending on which new products are introduced and on consumer preferences.

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[5] In particular, the defining characteristic of vertical models is that consumers agree on the rank ordering of product attribute importance such that "were any two goods in question offered at the same price, then all consumers would agree in choosing the same one." The defining characteristic of horizontal models is that "consumers would differ as to their preferred choice if all the goods in question were offered at the same price" (for these definitions, see Shaked and Sutton 1983; Schmalensee and Thisse 1988, pp. 1469 and 228, respectively). In reality, there may be contexts where both types of differentiation are present at the same time. Our analysis here examines each separately to better understand the forces that arise in each case.

[6] Allowing $\frac{1}{2} < \alpha < 1$ would merely reverse the roles of attributes a and b.

[7] In §5, we discuss an extension to the vertical preferences case that allows for heterogeneity in consumer willingness to pay (WTP). But the market uncertainty would still be about which attribute all consumers prefer.

LEMMA 1. *In the pricing subgame, having chosen to attempt innovation on attribute j, firm i's price $p_j(i)$ and profits $\pi_j(i)$ will be*

V, if it is the sole innovator and consumers prefer attribute j;

$V - D$, if it is the sole innovator and consumers prefer attribute j' ($j' \neq j$);

D, if it innovates on j, its rival innovates on j', and consumers prefer attribute j; and

0, otherwise.

A firm can thus attain one of four profit levels depending on the outcome at $t = 2$. Note that if $D > V/2$, profits from innovating on the preferred attribute and facing competition from a firm that innovated on the less preferred attribute are higher than profits from innovating on the less favored attribute and facing no competition. In the limit $D \to V$, innovation on the less preferred attribute is worthless.

By conducting market research, a firm discovers which attribute consumers value more. Based on Lemma 1, we establish the following result about an informed firm's innovation strategy.

LEMMA 2. *A dominant strategy for an informed firm is to attempt innovation on the attribute it discovered to be more valued by consumers.*

A firm that conducts market research will therefore always pursue innovation on the attribute discovered to be of maximal value to consumers. Regardless of the attribute pursued by a rival, a firm's expected profits will always be greater with a new product that embodies innovation on the most valued attribute.

Before characterizing the equilibria in the duopoly case, we seek insights by solving for the optimal actions of a monopolist. This allows us to isolate a firm's incentives when competitive concerns are absent.

PROPOSITION 1. *There exists a cutoff value C^m such that if the market research cost satisfies $C \leq C^m$, a monopolist conducts market research and attempts innovation on the preferred attribute. If $C^m \leq C$, a monopolist forgoes market research and attempts innovation on the safer attribute b. The R&D level of an uninformed monopolist is smaller than that of an informed monopolist.*

For a monopolist, the trade-off in conducting market research is clear: a market study is costly but guarantees innovation efforts are directed to the attribute that consumers prefer and that yield the highest possible rents (V). Hence, if the benefit to being informed is greater than the cost, the monopolist commissions market research. Proposition 1 further reveals that an uninformed monopolist always finds it beneficial to innovate on the safer attribute (b). The solution demonstrates an interplay between market research and the R&D level chosen. Because market research

enhances the productivity of R&D by directing the effort towards a reward of V rather than a smaller expected reward of $V - \alpha D$, when the firm is uninformed, a higher R&D level is selected.[8]

We make the following observations about the monopolist's optimal R&D levels, $\varphi_c = V/K$ when informed, and $\varphi_b = (V - \alpha D)/K$ when uninformed. Both levels increase in V, the maximal value of innovation to consumers, and decrease in K, the difficulty of achieving R&D success. Intuitively, V increases the expected payoffs from R&D effort and K decreases them, regardless of whether the monopolist is informed. The parameters α and D, however, are only relevant for the uninformed monopolist, which attempts innovation on the safer attribute b, yet with probability α its R&D efforts are directed towards the less valued attribute and it will price at $V - D$. As a result, the uninformed monopolist lowers its R&D level as α and D increase.

3.1. Market Research and Competition
We now turn to the case of two competing firms planning to develop new products. We expand our notation such that for a given variable the first subscript denotes the attribute the firm has chosen to innovate on, while the second subscript denotes the attribute the rival has chosen. Following a similar convention, we use two superscripts to denote whether the firms have elected to conduct market research. For example, we write φ_{bc}^{01} for the R&D level of a firm that did not conduct market research ($mr = 0$) and chose to innovate on attribute $j = b$, facing a rival that has conducted market research ($mr' = 1$) and that chose to innovate on the attribute it discovered to be preferred by consumers ($j' = c$). In this case, the R&D level of the rival firm that conducted market research will be denoted φ_{cb}^{10}. We solve for the pure-strategy perfect Bayesian Nash equilibria of the game (Fudenberg and Tirole 1991).[9]

3.1.1. Market Research and the Direction of R&D Effort.
In Lemma 1, we established the pricing equilibrium in the final subgame depending on which

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[8] The informed monopolist's optimal strategy implies that its R&D level will be the same ($\varphi_c = V/K$) regardless of which attribute (a or b) is discovered to be preferred. For the sake of clarity, we note that if a monopolist conducts market research and attempts to innovate on the less preferred attribute, then because it knows with certainty that consumers will only place a value of $V - D$ on this innovation, it would set an R&D level of $\varphi_{\bar{c}} = (V - D)/K$. But this results in lower expected payoffs than attempting innovation on the preferred attribute.

[9] We define the game as Bayesian because firms need to form beliefs about the underlying state of demand (which are updated if the firm conducts market research). In our case, the beliefs of an uninformed firm are the same on and off the equilibrium path ($\mu(a) = \alpha$, where $\mu(a)$ is the belief that consumers prefer attribute a); hence for the rest of the game we can focus on strategies only.

new products were introduced and on consumer preferences. We now characterize the equilibria of the entire game in terms of the decision to conduct market research and the choice of which attribute to attempt innovation on. In the next subsection, we provide more details about the R&D levels selected. A strategy profile $\sigma = \{\sigma(1), \sigma(2)\}$, $\sigma(i) = \{mr(i), j(i), \varphi_j(i), p(i)\}$ $i \in \{1, 2\}$, will form an equilibrium if, taking its rival's strategy as given, each firm's expected payoffs cannot be increased by unilaterally deviating to an alternative strategy.

PROPOSITION 2. *There exist cutoff values $0 < C^{01} < C^{11} < C^{00} < C^{10}$ for the market research cost C such that the following equilibria of the game exist:*

(1) *Dual-market-research equilibrium: If $C \leq C^{11}$, both firms conduct market research and attempt innovation on the most valued attribute.*

(2) *Single-market-research equilibrium: If $C^{01} \leq C \leq C^{10}$, only one firm conducts market research and it attempts innovation on the most valued attribute. For the uninformed firm, attempting innovation on the safer attribute b is always an equilibrium; under certain conditions, attempting innovation on attribute a may also be feasible.*

(3) *No-market-research equilibrium: If $C^{00} \leq C$, neither firm conducts market research. Either both firms attempt innovation on the safer attribute or separate attributes.*

The various equilibria in terms of conducting market research are depicted in Figure 1. Note that multiple equilibria may coexist as the single-market-research region overlaps the other two.

In understanding the intuition behind Proposition 2 note that, as in the monopoly case, the trade-off between the benefit of learning which attribute is preferred by consumers (related to αD) and the cost of acquiring the information (C) remains. However, with competition there is an added consideration: the benefit of conducting market research decreases if the rival firm conducts market research as well. This is because of the correlating feature of market research: with vertical preferences two informed firms will unavoidably attempt innovation on the same attribute (per Lemma 2). If the R&D efforts of both are successful, the new products introduced will not be differentiated (leading to zero profits per Lemma 1).

We can now explain in greater detail the intuition behind each equilibrium region and formalize each

firm's choice of which attribute to attempt innovation on. We begin with regions (1) and (3) of Proposition 2 and then discuss region (2).

(1) **Dual-market-research equilibrium** ($C \leq C^{11}$). The informational benefit associated with innovating on the preferred attribute outweighs the relatively low cost of market research and an equilibrium whereby each firm conducts market research can be sustained. We note that because market research will correlate the two firms' innovation paths, which lowers the benefit of being informed relative to a monopolist, we will have $C^{11} < C^m$.[10]

(3) **No-market-research equilibrium** ($C^{00} \leq C$). When market research is prohibitively costly, an equilibrium in which neither firm conducts market research can be sustained. In this case, two types of equilibria can arise in the choice of which attribute to attempt innovation on, and the existence of each depends on the development cost factor K as follows.

RESULT 1. *If neither firm conducts market research, there exist values $\underline{K}$ and $\overline{K}$ such that for*

$K < \underline{K}$, *the unique equilibrium is asymmetric: one firm chooses attribute a and the other b,*
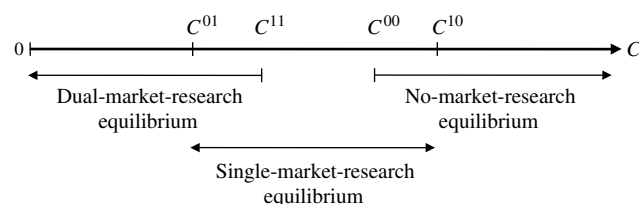
$\underline{K} \leq K \leq \overline{K}$, *two equilibria coexist: a symmetric one with both firms choosing attribute b, and an asymmetric one with each firm choosing a separate attribute,*

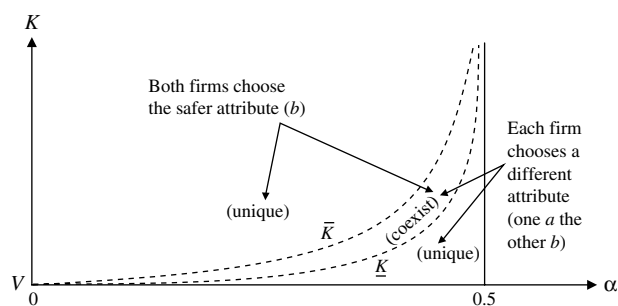$\overline{K} < K$, *the unique equilibrium is symmetric: both firms choose attribute b.*

$\underline{K}$ *and* $\overline{K}$ ($\underline{K} \leq \overline{K}$) *are nondecreasing functions of α, with $\lim_{\alpha \to 1/2} \underline{K} = \lim_{\alpha \to 1/2} \overline{K} = +\infty$.*

When neither firm is willing to incur the high cost of market research, Result 1 reveals an interesting pattern for the attribute each firm attempts to innovate. Like the monopolist (Proposition 1), an uninformed firm has an incentive to choose the safer attribute (b) given that it is a priori more likely to be the preferred attribute—we call this the *uncertainty-avoidance* effect. But duopolists also have to consider the implications of attribute choice on downstream product market competition. In particular, there is a force driving firms to innovate on separate attributes so that they do not end up competing profits away in the event that their R&D efforts jointly succeed. We call this the *differentiation* effect. If K is small, all else equal,

Figure 1   **Equilibria as a Function of Market Research Cost** C

Figure 2   Choice of Attribute to Innovate on in the No-Market-Research Equilibria

firms tend to select high R&D levels and their innovation efforts will likely succeed. Choosing to innovate on the same attribute will result in both firms introducing identical new products with high probability leading to zero profits (Lemma 1). Thus, when $K < \underline{K}$ and technical uncertainty is low, the differentiation effect dominates and the uninformed firms prefer to gamble on separate attributes, each hoping it has guessed correctly. However, when K is large, firms tend to select relatively low R&D levels and technical uncertainty is substantial. Each firm is then less concerned with the success of its rival's R&D efforts and would rather pick the safer attribute; i.e., uncertainty avoidance dominates.

Figure 2 depicts Result 1 graphically. Note the interplay between the degree of market uncertainty and the degree of technology development difficulty. As α increases, uncertainty avoidance becomes less pronounced, and we can sustain differentiated innovation paths for higher values of the development cost factor K.

(2) **Single-market-research equilibrium** ($C^{01} \leq C \leq C^{10}$)**.** In this range we get the intriguing result whereby the two, otherwise identical, firms pursue asymmetric strategies at the outset. In this equilibrium, therefore, the firms have different knowledge about the demand when deciding which attribute to attempt innovation on and how aggressively to set R&D. This equilibrium occurs because of a combination of factors outlined earlier. When one firm conducts market research, the benefit to that firm of being informed is high and outweighs the cost (C) that is in a mid-range. However, the uninformed firm does not want to deviate and conduct market research because the value of the information will be relatively low because, as explained earlier, the two firms will then select the same attribute. Thus, the benefit of conducting market research is clear for one firm but is outweighed by the cost for the second firm.

The firm that conducted market research does not need to gamble on which innovation path to pursue as it will direct R&D efforts to the attribute that consumers value more (Lemma 2). The uninformed firm, however, has to choose its innovation path using only

the ex ante prior. Although uncertainty avoidance always makes the choice of attribute b an equilibrium strategy, under certain conditions the uninformed firm may take a chance on attribute a.

RESULT 2. There exists a single-market-research equilibrium where the uninformed firm:

(1) attempts innovation on the safer attribute ($j = b$) $\forall \alpha$; this equilibrium is unique for $\alpha < \bar{\alpha}$, and

(2) attempts innovation on the riskier attribute ($j = a$) if $\bar{\alpha} \leq \alpha < \frac{1}{2}$.

To understand the intuition, note that the uninformed firm earns positive profits only when the informed firm's R&D efforts fail (Lemma 1). Also note that the informed firm invests more in R&D when it discovers through market research that the uninformed rival's equilibrium strategy is to attempt innovation on the less preferred attribute (because in the event that both succeed in R&D, the informed firm still makes positive profits). Assume first that the uninformed firm is expected in equilibrium to innovate on attribute a. In considering whether to deviate to attribute b, the uninformed firm takes into account two possibilities: (1) The informed firm discovered that attribute a is the preferred attribute. The uninformed firm would thus be deviating to the less valued attribute, reducing potential profits by D. (2) The informed firm discovered that attribute b is the preferred attribute. The uninformed firm would thus be deviating to the more valued attribute, increasing its potential profits by D. But in this latter case, the informed firm will be investing heavily because it believes (according to the equilibrium) that it is attempting innovation on a different attribute than the one chosen by the uninformed rival. This, in turn, reduces the chances of the uninformed firm earning positive profits by being the sole innovator. These considerations create an overall disincentive to deviate. Another way to think about why this equilibrium can hold is that the uninformed firm believes (given the prior) that it is more likely that the informed rival will attempt innovation on attribute b, and hence it can be a viable strategy to bet on a different attribute. This is similar in some sense to the dilemma facing a participant in a lottery jackpot when there is a lucky number that many are expected to select. If the odds are not too unfavorable (in our case, α not too close to zero), it may be beneficial to gamble on a different number and avoid having to share the prize with other participants.[11]

If according to the equilibrium being played the uninformed firm is expected to attempt innovation on attribute b, then uncertainty avoidance creates an added disincentive for it to switch to attribute a.

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[11] We thank an anonymous reviewer for providing us with this intuitive analogy.

As α moves away from $\frac{1}{2}$, uncertainty avoidance further reinforces considerations to not deviate when attribute b is chosen in the proposed equilibrium, but works against the incentives for not deviating when attribute a is chosen. Therefore, we can always sustain a single-market-research equilibrium with the uninformed firm choosing the safer attribute b, but we require α close to $\frac{1}{2}$ to sustain the choice of attribute a.

3.1.2. Market Research and the Level of R&D Effort. We now examine the R&D levels firms select in the different equilibria of Proposition 2. In particular, we want to understand how facing an informed rival affects the incentives to undertake R&D and whether two informed firms invest more or less than two uninformed firms. Last, we want to understand how the different R&D levels depend on the model's parameters. To gain insight into the strategic considerations involved in R&D level selection, we first establish the following lemma.

Lemma 3. *R&D levels always form strategic substitutes.*

Strategic substitutability (Bulow et al. 1985) means that the marginal return to a firm from its own R&D level is decreasing in the rival's R&D level (mathematically, $\partial^2 E\pi(i)/\partial\varphi(i)\partial\varphi(i') < 0$). This is intuitive with vertical preferences. When the rival's R&D level increases, the firm is more likely to earn duopoly rather than monopoly rewards. As this reduces expected payoffs, the firm's marginal return on R&D decreases. The implication of Lemma 3 is that when a competitor is more aggressive in R&D, this creates an incentive for the firm to be less aggressive in R&D. The following proposition provides the ordering of the various R&D intensities.

Proposition 3. *Let $\varphi_{j,j'}^{mr,\,mr'}$ denote the R&D level of a firm given its market research decision (mr) and attribute choice (j), as well as those of its rival (mr' and j'). The R&D levels in the different equilibria are ranked as follows:*

(1) *in the uninformed firm cases:* $\varphi_{ac}^{01} < \varphi_{bc}^{01} < \varphi_{ab}^{00} < \varphi_{bb}^{00} < \varphi_{ba}^{00}$,

(2) *in the informed firm cases:* $\varphi_{cc}^{11} < \varphi_{bb}^{10} < \varphi_{aa}^{10} < \varphi_{ab}^{10} < \varphi_{ba}^{10}$, *and*

(3) *all the R&D levels in the uninformed firm cases are smaller than the R&D levels in the informed firm cases, except when $\alpha < \alpha^*$, $\alpha^* \in (0, \frac{1}{2})$, we have $\varphi_{ba}^{00} > \varphi_{cc}^{11}$.*

First, Proposition 3 reveals that an informed firm always selects a higher R&D level than an uninformed rival. In addition, an informed firm's R&D level is more aggressive when the uninformed rival's equilibrium strategy is to attempt innovation on the attribute that was discovered to be less preferred (e.g., if $c = a$ then $\varphi_{aa}^{10} < \varphi_{ab}^{10}$). In this case, the informed

firm receives profits of V or D if its R&D efforts succeed, compared to V or 0 if it had turned out that the uninformed rival was also attempting innovation on the preferred attribute. The highest R&D level is φ_{ba}^{10}, because when the uninformed firm chooses attribute a rather than b, the smaller expected returns (since $\alpha < \frac{1}{2}$) induce it to select a lower R&D level. Because of strategic substitutability, the informed firm reacts by investing more. Note that conducting market research affects the R&D decision even holding attribute choices constant; specifically, the informed firm selects a higher R&D level than it would have selected in a no-market-research equilibrium gambling on the same attribute (e.g., if $c = b$ and $j' = a$, then $\varphi_{ba}^{00} < \varphi_{ba}^{10}$).

Second, and more surprising, when both firms are uninformed and choose separate attributes, the R&D level φ_{ba}^{00} can be higher than the R&D level φ_{cc}^{11} when both firms are informed (see Proposition 3, part (3)). This happens because the firm innovating on the safer attribute b has a higher expected payoff than the firm innovating on attribute a, hence in equilibrium $\varphi_{ab}^{00} < \varphi_{ba}^{00}$. As α moves away from $\frac{1}{2}$, the firm innovating on the safer attribute faces an even softer competitor, and because R&D intensities are strategic substitutes, it selects a more aggressive R&D level; i.e., φ_{ba}^{00} increases. If α is below some threshold, this level will be higher than that of the firms in the dual-market-research equilibrium. In the latter case, although both firms know they are attempting innovation on the preferred attribute, the prospects of head-to-head competition have a dampening effect on the incentives to undertake R&D.

To understand how the R&D levels are affected by changes in the model's parameters, one needs to decompose their equilibrium adjustment into direct and strategic effects. The direct effect is related to the sensitivity of a firm's expected payoffs to a change in a parameter, while keeping the R&D intensity of the rival fixed. The strategic effect is related to the sensitivity of a firm's expected payoffs to the rival's R&D response to the parameter change (Tirole 1988). We highlight the key comparative statics (a complete list appears in the appendix, Table A.1).

The direct effect of increasing the maximal value of innovation for consumers (V) is always positive, while that of increasing the development cost factor (K) is always negative. But in the single-market-research equilibria, these direct effects are more pronounced for the informed firm that knows the consumer preferred attribute when selecting its R&D level. The disparity in the magnitude of direct effects across the firms results in a negative strategic effect for the uninformed firm, which can be large enough to overshadow its positive direct effect so that φ_{jc}^{01} decreases in V and increases in K. Similarly, in the

no-market-research equilibrium when firms differentiate, the same logic explains why the firm that chooses the more uncertain attribute a may decrease (increase) its R&D level as $V(K)$ increases.

With respect to the disutility parameter, in the single-market-research equilibrium the two firms react differently to an increase in D. This is because the direct effect of an increase in D is negative for the uninformed firm (a payoff of $V - D$ if it innovates successfully on the less preferred attribute and the informed rival fails); this produces a positive strategic effect for the informed firm.[12] With respect to the degree of market uncertainty, an increase in α makes attribute a more likely to be preferred. For an uninformed firm, this produces a positive direct effect when innovating on attribute a and a negative direct effect when innovating on attribute b. In the single-market-research equilibria, there is no direct effect for the informed firm, which has resolved the market uncertainty. As the informed firm only has a strategic effect, its R&D sensitivity to α will in all cases be opposite to that of the uninformed firm. For example, in an equilibrium in which the uninformed firm attempts innovation on attribute b, the informed firm's R&D level (φ_{cb}^{10}) will increase in α.

It is instructive to compare these last findings with the monopoly solution. Recall that an informed monopolist's R&D level does not depend on the degree of market uncertainty α or on the disutility parameter D. With competition, however, this is no longer true. When a firm is informed but its rival is not, strategic effects arise and create a dependence on these parameters.

3.1.3. When Neither Attribute Is Perceived Ex Ante Safer ($\alpha = \frac{1}{2}$). We conclude this section by examining the special case of $\alpha = \frac{1}{2}$. Because neither attribute has ex ante greater likelihood of being more valued by consumers, uncertainty avoidance does not play a role. The only change in the monopoly case is that when uninformed, the firm is indifferent between attributes a and b and would attain equal expected payoffs from attempting innovation on either. As for the competitive context, all three types of equilibria in market research exist, as laid out in Proposition 2. They have the following characteristics:

Dual-market-research equilibrium. Both firms pursue the attribute discovered through market research to be most valued by consumers. (No change.)

Single-market-research equilibrium. The informed firm pursues the attribute it discovered to be most valued by consumers. Two pure-strategy equilibria coexist, the uninformed firm attempts innovation on attribute a or on attribute b.

No-market-research equilibrium. Each firm attempts innovation on a separate attribute.

Thus, when at least one firm forgoes market research, because only the differentiation effect is present, we should expect more divergence in terms of the new products firms attempt to develop than when $\alpha < \frac{1}{2}$.[13]

4. Horizontal Preferences over the Attribute Space

In this section, we study the case in which a portion s_b of consumers only value innovation on attribute b and the remaining $s_a = 1 - s_b$ of consumers only value innovation on attribute a. For consumers in the former segment, innovation on attribute b yields utility (net of price) of V and innovation on attribute a yields zero utility. The reverse is true for consumers in the latter segment, for which innovation on attribute a yields utility of V and innovation on attribute b yields zero utility. Hence, a new product with innovation on attribute b is horizontally differentiated from a new product with innovation on attribute a.

Ex ante firms do not know the size of the segments; i.e., they face market uncertainty about how many consumers value each type of innovation. At the outset of the game, firms treat s_b as a random variable. Let $\tilde{s}_b$ be distributed over $[0, 1]$ with cumulative distribution function F and probability density function f. We assume that F is differentiable and that firms' prior is that the segments are of equal size, $E[\tilde{s}_b] = \frac{1}{2}$.[14] If a firm conducts market research, at cost C_s, it learns the value of s_b.

The structure of the game remains the same as described in the model setup (§2), and we solve for pure-strategy equilibria as before (starting from the pricing subgame backward). The following lemma gives the prices and profits that arise in equilibrium in the final subgame.

Lemma 4. *In the pricing subgame, having chosen to attempt to innovate on attribute j, firm i's price $p_j(i)$ and profits $\pi_j(i)$ will be*

$p_b(i) = V$, $\pi_b(i) = s_b V$, *if firm i is the sole innovator on attribute b;*

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[12] φ_{ab}^{10} and φ_{ba}^{10} also have a positive direct effect—a payoff of D when the uninformed rival innovates successfully.

[13] R&D intensities still form strategic substitutes and will have a similar ranking as that in Proposition 3: $\varphi_{jc}^{01} < \varphi_{jj'}^{00} < \varphi_{cc}^{11} < \varphi_{jj}^{10} < \varphi_{jj'}^{10}$. Note that firms unequivocally invest more in R&D in the dual-market-research case than in the no-market-research case, which is consistent with the condition on α in Proposition 3. We thank the area editor for suggesting that we separately present the case of $\alpha = \frac{1}{2}$.

[14] Assuming $E[\tilde{s}_b] \neq \frac{1}{2}$ does not affect the central results of this section. For example, if $E[\tilde{s}_b] > \frac{1}{2}$, an uninformed firm would have a greater incentive to target segment b. But as long as $\text{Var}[\tilde{s}_b] > 0$, the behavior of an informed firm still follows the pattern described in Proposition 5 and Results 3 and 4.

$p_a(i) = V$, $\pi_a(i) = (1 - s_b)V$, if firm i is the sole innovator on attribute a; and

$p_j(i) = 0$, $\pi_j(i) = 0$, otherwise.

From Lemma 4, we see that with segments that differ in their horizontal tastes both firms will make positive profits when they successfully innovate on separate attributes. In particular, the firm that innovates on attribute b caters to a segment of size s_b and earns profits of $s_b V$, while its rival caters to a segment of size s_a and earns profits of $(1 - s_b)V$. Recall that both firms earning positive profits in equilibrium was not feasible in the previous type of preference structure. It is also evident that only three profit levels are possible in this case because when firms innovate on different attributes their profits are independent of each other.

We proceed in a similar fashion to the previous section by first examining the monopoly benchmark case and then analyzing the competitive context.

PROPOSITION 4. *There exists a cutoff value C_s^m such that if the market research cost satisfies $C_s \leq C_s^m$, a monopolist conducts market research and attempts innovation on the attribute that appeals to the larger segment. If $C_s^m \leq C_s$, a monopolist forgoes market research and attempts innovation on either attribute. The R&D level of an uninformed monopolist is smaller than that of an informed monopolist.*

The monopolist's decision rule about market research has a very similar flavor to that with vertical preferences (per Proposition 1). The cutoff C_s^m is determined by the expected benefit of learning the segment sizes (proportional to $E[\max(s_b, 1 - s_b)]^2 - \frac{1}{4}$). It is clear that an informed monopolist unequivocally chooses to attempt innovation on the attribute valued by more consumers (analogous to the previous outcome of having a dominant strategy to choose the more valued attribute). The informed monopolist's R&D level ($\varphi_c = (\max(s_b, 1 - s_b)V)/K$) depends on the exact value of s_b; hence the value of market research for the monopolist is twofold. First, it allows choosing the attribute that appeals to the larger segment. Second, it allows gauging the exact return from an innovation along that attribute so as to set the optimal R&D level.

4.1. Market Research and Competition

Next we examine the competitive case. As the next proposition will show, with horizontal tastes we can still sustain the three types of equilibria in market research as in the previous analysis. Note, however, that a firm that conducts market research may in equilibrium pursue the innovation route that targets the smaller of the two segments, yielding lower market share and postlaunch profits than its rival can achieve.

PROPOSITION 5. *There exist cutoff values $0 < C_s^{01} < C_s^{11} < C_s^{00} < C_s^{10}$ for the market research cost C such that the equilibria of the game are as follows:*

(1) *Dual-market-research equilibrium: If $C_s \leq C_s^{11}$, both firms conduct market research. Firms either both attempt innovation on the attribute that appeals to the larger segment or pursue separate attributes.*

(2) *Single-market-research equilibrium: If $C_s^{01} \leq C_s \leq C_s^{10}$, only one firm conducts market research. The uninformed firm is indifferent between attempting innovation on attribute a or b, while the informed firm attempts innovation on the attribute that appeals to the larger or the smaller segment.*

(3) *No-market-research equilibrium: If $C_s^{00} \leq C_s$, neither firm conducts market research. Firms pursue separate attributes: One firm attempts innovation on attribute a, and the other b.*

To understand the intuition for the different equilibria, in particular the attribute each firm chooses to innovate, we need to recognize that with the horizontal demand structure two forces exist: a *segment-size* effect and a *differentiation* effect. The former effect is relevant only for an informed firm that knows how big the consumer segments are, and drives it to target the larger segment because of the higher rewards if it is the sole innovator on the attribute that this segment cares about. The latter effect drives a firm to select a different attribute than its rival to avoid harsh price competition in case both firms successfully develop new products. By serving a distinct segment, a firm is guaranteed positive profits if its R&D efforts succeed (Lemma 4). Note that the differentiation effect is also relevant for an informed firm. By contrast, recall that with vertical preferences once a firm learns the preferred attribute its dominant strategy is to pursue that attribute regardless of the rival's actions (Lemma 2). Using these forces, we now explain the intuition for each of the equilibria.

(1) **Dual-market-research equilibrium.** When the cost of market research is small, both firms will conduct market research as there is always a benefit in learning the value of s_b. Because of the segment size effect, at least one firm will target the larger of the two segments. But the best response of the other firm depends on the interplay between the segment-size and differentiation effects, as characterized by the following result.

RESULT 3. If both firms conduct market research there exist $\underline{s}_b$, $\bar{s}_b$ ($\frac{1}{2} < \underline{s}_b < \bar{s}_b < 1$) such that

—both firms attempting innovation on attribute b is an equilibrium iff $\underline{s}_b \leq s_b$,

—each firm attempting innovation on a separate attribute is an equilibrium iff $1 - \bar{s}_b \leq s_b \leq \bar{s}_b$, and

—both firms attempting innovation on attribute a is an equilibrium iff $s_b \leq 1 - \underline{s}_b$.

$\underline{s}_b$ and $\bar{s}_b$ increase as K decreases.

Figure 3   The Possible Dual-Market-Research Equilibria Depending on Segment Sizes
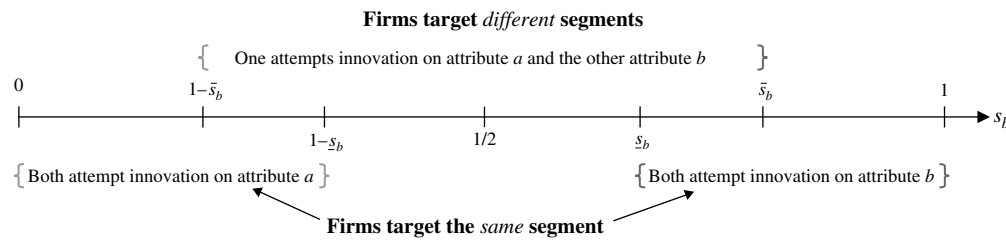

Figure 3 depicts the regions for the various equilibria to hold. Intuitively, when the firms learn that one segment is substantially larger, the segment-size effect dominates, and both firms will target their innovative efforts to serve this segment. If s_b is very close to one both will attempt innovation on attribute b. If s_b is very close to zero both will focus on attribute a. Market research thus positively correlates the firms' innovation paths when it reveals that the majority of consumers fall in one of the segments.

The interesting equilibrium in attribute choices occurs when the segments are discovered not to be very dissimilar in size. In this case, market research actually negatively correlates the firms' innovation paths. In particular, if the firms learn that $s_b \in (\frac{1}{2}, \bar{s}_b)$, one firm will definitely attempt innovation on attribute b, the attribute valued by the larger segment. Given that the rewards are higher from innovation that serves this segment, this firm will select an aggressive R&D level and is likely to succeed in introducing a new product. Consequently, an equilibrium will exist where the rival, who is also informed, prefers to avoid competing for the same set of customers and instead has a best response of pursuing innovation that targets the other segment, *even though it is smaller and generates less profits* than can be earned by exclusively serving the large segment. The mirror situation will occur, of course, if the firms learn that $s_b \in (1 - \bar{s}_b, \frac{1}{2})$, in which case one firm will target the larger segment that values innovation on attribute a and the rival's best response is to target the smaller segment that values attribute b.

To summarize, if firms discover that s_b is in an intermediate range, the differentiation effect prevails over the segment-size effect. Hence, it is possible for identical firms, facing ex ante equally profitable innovation paths, to both conduct market research but end up differentiating in their choice of which attribute to pursue. As is clear from Figure 3, this type of equilibrium is unique when the segment sizes are discovered to be in the range $1 - \underline{s}_b < s_b < \underline{s}_b$. The cutoffs $\underline{s}_b$ and $\bar{s}_b$ increase as development becomes less costly. As K decreases, the firms are induced to select higher R&D levels and are more likely to succeed in their development efforts; hence the chances of making positive profits by pursuing innovation that targets

the same segment diminish and the differentiation effect becomes even stronger. Notably, for low values of K we have $\bar{s}_b \to 1$, and we can sustain the asymmetric equilibrium in the attributes chosen even when one of the segments is quite small compared to the other.

(2) **Single-market-research equilibrium.** Market research may reveal that the bulk of consumers value innovation on a particular attribute (s_b close to 1 or 0). In that case, as we know from Result 3, when both firms are informed they will target the larger segment,[15] and if the R&D efforts of both succeed, profits will be zero (Lemma 4). Hence, even with horizontal preferences, when one firm is informed this reduces the expected value of information for the rival. Consequently, as C_s increases, at some point one firm will forgo market research. In this case we can sustain two equilibria in pure strategies for the uninformed firm, in one the uninformed firm attempts innovation on attribute a and in the other it attempts innovation on attribute b. The informed firm learns the value of s_b and has to decide whether to pursue the same attribute that the uninformed firm is expected to choose in equilibrium.[16] The following result characterizes the informed firm's equilibrium strategy.

RESULT 4. In a single-market-research equilibrium, there exists a value $\hat{s}_b$ ($\frac{1}{2} < \hat{s}_b < 1$) such that the informed firm will attempt innovation on

—attribute b: if $\hat{s}_b < s_b$,

—a different attribute than the one its rival is expected to choose: if $1 - \hat{s}_b < s_b < \hat{s}_b$, and

—attribute a: if $s_b < 1 - \hat{s}_b$.

The informed firm's decision is governed by the trade-off between the segment-size and differentiation effects. If it discovers that one segment is very large compared to the other, it will target that segment irrespective of the uninformed firm's strategy. However,

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[15] The ex ante probability that two informed firms will pursue the same attribute is $1 - F(\underline{s}_b) + F(1 - \underline{s}_b)$.

[16] Recall that in equilibrium each firm takes the rival's strategy as given and must prefer to follow its proposed strategy. In this case, the uninformed firm attempts innovation on one of the attributes and selects an R&D level, $\sigma'^*(\text{uninformed}) = \{mr = 0, j', \varphi_{j'}\}$. The informed firm's equilibrium strategy $\sigma'^*(\text{informed}) = \{mr = 1, j(s_b), \varphi_j(s_b)\}$ depends on what it learns from market research and is a best response to $\sigma'^*(\text{uninformed})$.

if the segment that values innovation on attribute b is neither too large nor too small relative to the segment that values innovation on attribute a $(1 - \hat{s}_b < s_b < \hat{s}_b)$, then the informed firm's best response is to differentiate. The informed firm is better off acting this way, even if this means lower rewards than it could earn as a monopolist serving the larger segment, to avoid a situation where competition drives profits to zero if the rival also succeeds in development.

We make two observations. First, recall that an informed monopolist (Proposition 4) would always target the larger of the two segments. However, with competition we see that a single informed firm that has incurred the cost of market research and learned the structure of demand may knowingly follow a niche innovation strategy and target the smaller segment. This happens when the informed firm realizes that its uninformed rival is betting on the attribute valued by the majority of consumers, and the niche segment is not too small. Second, this result is in contrast to the vertical preferences model where an informed firm always chooses the attribute it discovers consumers prefer, irrespective of the rival's strategy.[17]

(3) **No-market-research equilibrium.** The value of being informed is bounded from above, so when the cost is high neither firm conducts market research in equilibrium. Given that the segments are of a priori equal size, only the differentiation effect is relevant and each firm attempts innovation on a separate attribute. Thus, when neither firm conducts market research and R&D efforts succeed, we should expect distinct new products to be launched, each catering to a different segment. Ex post (except for knife-edge cases) one firm will do better than its rival given the realization of consumer preferences, but both firms will earn positive profits.

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[17] The classic result by de Palma et al. (1985) that firms want to agglomerate (i.e., minimally differentiate) can be contrasted with our results here. In their paper, firms choose their spatial location on a linear city (i.e., mix of attributes) and consumers have heterogenous tastes and transportation costs. Firms do not observe consumer tastes and use a probability distribution for the choice each individual makes. Firms agglomerate at the center of the line when the importance of taste is large compared to the transportation cost. In our model, however, when firms conduct market research (and hence can observe the makeup of demand) agglomeration occurs if consumer tastes are relatively homogeneous (i.e., one of the segments is by far the largest), even though the rival is expected to innovate for that segment as well. Finally, d'Aspremont et al. (1979) show that firms want to differentiate when demand is uniformly distributed and they know the location of each consumer. That is firms differentiate to soften price competition. In our model, the distribution has two focal attributes. A firm that conducts market research has an incentive to attempt innovation for the largest segment, and this may lead to agglomeration as explained above. The informed firm will consider a differentiation strategy for similar reasons as in d'Aspremont et al. (1979), but only if it discovers that the segment sizes are not too dissimilar.

Note that this outcome is similar in some respects to that analyzed in §3.1.3 with each attribute ex ante equally likely to be more valued by all consumers $(\alpha = \frac{1}{2})$. There, when neither firm conducted market research firms also chose differentiated innovation paths. However, unlike the horizontal preferences, ex post only one firm would have bet correctly on the most valued attribute and earned positive profits.

4.1.1. Market Research and the Level of R&D Effort. Thus far we have focused on the value of being informed in terms of the innovation path selected. Two benefits emerged: Market research could reveal that one segment is so large that it only makes sense to target that segment (even if the rival is innovating for the same segment), or it could reveal that the segments are not too dissimilar in size and hence it makes more sense to differentiate. Yet another benefit of market research is the ability to adjust R&D levels to the exact size of the segments (s_j), leading to an investment that optimally matches the return. The next result characterizes how R&D levels are affected by the information from market research.

RESULT 5. In a single-market-research equilibrium, the informed firm's R&D level is initially decreasing and then increasing in s_b. In the dual-market-research equilibrium, there exists a region where the R&D levels of the firms exhibit diverging patterns, increasing for one firm and decreasing for the other, as s_b increases.

The intuition for this result is as follows. When an informed firm learns that $s_b = 0$, i.e., all consumers only value innovation on attribute a, its R&D efforts will surely be directed to that attribute. As s_b initially increases, this implies that the segment being targeted is decreasing in size (since $s_a = 1 - s_b$), and this lowers the R&D level. As s_b increases further, at some point the informed firm will switch to attempting innovation on attribute b (the exact point will depend on which attribute the uninformed firm chooses). From there on, the greater s_b is discovered to be the more the firm will invest in R&D. When both firms conduct market research, recall from Result 3 that there exists a range of s_b $(s_b \in [1 - \bar{s}_b, \bar{s}_b])$ in which each firm targets a different segment. In this region, the firm attempting innovation on attribute b selects an R&D level of $\varphi_{ba}^{11} = s_b(V/K)$ and its rival selects an R&D level of $\varphi_{ab}^{11} = (1 - s_b)(V/K)$, which clearly leads to diverging patterns, i.e., increasing for the former level and decreasing for the latter, as s_b increases.

To examine how the R&D levels of the different equilibria of Proposition 5 compare to one another, it is useful to understand the strategic interaction between firms' R&D incentives.

LEMMA 5. *In any equilibrium in which the firms choose the same attribute to attempt innovation on, R&D levels*

will form strategic substitutes. In any equilibrium in which the firms choose different attributes to attempt innovation on, R&D levels will be strategically independent.

The first part of this lemma reflects the fact that when attempting innovation on the same attribute, each firm is strictly worse off if its rival's R&D efforts succeed (as profits will be zero). Hence, the higher the R&D level of the rival the less incentive a firm has to invest in R&D. The second part reflects the fact that when each firm attempts innovation for a different segment their payoffs are independent; hence there is no strategic interaction between their R&D levels. This latter outcome was not possible with vertical preferences for which, even when choosing different attributes, each firm's expected payoffs still depended on the success/failure of its rival's R&D. Note also that with horizontal preferences the only time firms attempt innovation on the same attribute when at least one of them has conducted market research (per Results 3 and 4). Therefore, strategic substitutability in this case is closely linked to the market research decision.

We will refer to the various R&D levels using the following notation. When a firm conducts market research, we denote with subscript c the attribute it learns is valued by the larger segment, and by $\bar{c}$ the attribute valued by the smaller segment. For example, if the firm learns that $\frac{1}{2} < s_b$, then $c = b$ and $\bar{c} = a$. Let s_c be the size of the larger segment ($s_c = \max\{s_b, 1 - s_b\}$). When a firm does not conduct market research, its R&D level is the same regardless of the attribute it chooses (given that $E[\tilde{s}_b] = \frac{1}{2}$). For simplicity, subscripts are omitted.[18]

PROPOSITION 6. *Let $\varphi_{j,j'}^{mr,mr'}$ denote the R&D level of a firm given its market research decision (mr) and attribute choice (j), as well as those of its rival (mr' and j'). The following relationships hold for the R&D levels in the different equilibria:*

(1) *in the uninformed firm cases:* φ^{01}; φ^{00},

(2) *in the informed firm cases:* $\varphi_{\bar{c}c}^{11} = \varphi_{\bar{c}c}^{10} < \varphi_{cc}^{11}$; $\varphi_{cc}^{10} < \varphi_{c\bar{c}}^{11} = \varphi_{c\bar{c}}^{10}$, *and*

(3) *For any K and V there exists a value $s_c^* \in (\frac{1}{2}, 1)$, such that for $s_c < s_c^*$ we have $\varphi^{00} > \varphi_{cc}^{10}$.*

We highlight two R&D orderings that sharply contrast with the vertical preferences case. First, an informed firm facing an uninformed rival may allocate fewer resources to R&D than two informed firms. This occurs when the former ends up selecting the niche strategy of innovating to serve the small

segment (see first inequality in Proposition 6, part (2)). The intuition is clear: Because the firm is informed and knowingly decides to serve the smaller segment, it is prompted to select a relatively low R&D level. Second, and more surprising, if market research reveals that the larger segment is not too big ($s_c < s_c^*$), the informed firm in the single-market-research equilibrium will invest less than two uninformed firms, even though the informed firm is attempting innovation for the larger segment (Proposition 6, part (3)). The intuition is that the informed firm realizes, according to the equilibrium being played, that its rival has chosen to innovate for the same segment and the prospects of downstream competition dampen its R&D incentives. By contrast, two uninformed firms always choose distinct attributes and will earn positive profits if their development efforts succeed, and hence select a greater R&D level. Note that in this region for s_c, the R&D level of two uninformed firms is also greater than that of two informed firms.[19] In sum, while with vertical preferences market research generally increases the return on R&D because the firm's efforts are directed to the more profitable innovation, with horizontal preferences this effect is qualified. Market research may induce the firm to direct effort in a way that decreases the return on R&D relative to what an uninformed firm expects to attain.

5. Model Extensions, Extra Analysis, and Limitations

Our model setup entails assumptions on the demand structure, the nature of R&D, and firm behavior. We have made these assumptions in an attempt to best capture the phenomena of interest while at the same time maintaining simplicity and tractability. We have also justified a number of assumptions based on evidence from practice. That said, we wish to discuss how modifying several key model characteristics affects our results. The formal analysis of these extensions appears in the Technical Appendix available at http://mktsci.pubs.informs.org. We indicate several remaining limitations at the end of this section.

5.1. Vertical Preferences with Heterogeneity in Willingness to Pay

With vertical preferences, all consumers agree on the ordering of the products from which they derive more utility (net of price). In our setup, we have followed

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[18] Note that in the single- and dual-market-research equilibria an informed firm correctly conjectures at $t = 1$ whether the attribute its rival chooses corresponds to the larger (c) or smaller ($\bar{c}$) segment. Because $E[\tilde{s}_b] = \frac{1}{2}$, there is no need to distinguish between $c = a$ versus $c = b$ in the informed firm cases (e.g., $\varphi_{aa}^{10} = \varphi_{bb}^{10} = \varphi_{cc}^{10}$).

[19] We show in the appendix that this R&D ordering, between two informed versus two uninformed firms, exists over a wider range. In particular, there exists a s_c^{**} ($s_c^* < s_c^{**} < 1$) such that for $s_c < s_c^{**}$ we have $\varphi^{00} > \varphi_{cc}^{11}$. We also show that, for a uniform distribution, if market research reveals that one segment is much larger, two informed firms invest less than the informed firm in the single-market-research equilibrium ($\varphi_{cc}^{11} < \varphi_{cc}^{10}$).

this convention but also assumed for simplicity that consumers are homogeneous with respect to their WTP for innovations. One might wonder how allowing heterogeneity in consumers' WTP (as in Shaked and Sutton 1982) affects our results.[20] In this case, a firm that innovates on the less valued attribute may earn positive profits by charging a low price and serving low WTP consumers. Our analysis shows that all reported equilibria in Proposition 2 can hold for a wide range of the parameter space. Notwithstanding, because the desire to differentiate can be stronger with heterogeneity, under certain conditions we can also sustain equilibria in which a firm undertakes market research and attempts innovation on the less valued attribute. For such equilibria to exist, the development cost factor (K) has to be low (so that each firm worries that its rival's R&D will succeed), and the disutility parameter (D) can be neither too high (otherwise, the profits from innovation of the less preferred attribute are very small) nor too low (otherwise, the two attributes are of similar value and duopoly competition is fierce). Note that in these equilibria, a firm's attribute strategy is irrespective of what the market research reveals. For example, in the only new single-market-research equilibrium the informed firm always attempts innovation on attribute a and the uninformed firm attempts to attribute b; the benefit of market research is the ability to adjust R&D level but not direction. However, with the horizontal preference structure, only *after* the firm learns the true segment sizes does it determine whether its innovation path will be positively or negatively correlated with that of its rival. Note also that R&D levels with vertical preferences always form strategic substitutes, even when there is heterogeneity in WTP. By contrast, with horizontal preferences there are cases where R&D levels are strategically independent (see Lemma 5). Hence, the R&D comparative statics differ across the two settings.

5.2. The Asymmetric Market Research Equilibrium and Sequential Moves

In our setup, firms simultaneously decide at $t = 1$ whether to conduct market research. We found that asymmetric equilibria can arise in the market research decision even when the two firms are identical from the outset. Although such an analysis does not designate which specific firm will be the one to conduct market research, from a game-theoretic standpoint our results imply that when firms play out the game they will correctly anticipate each other's moves and act accordingly; one firm will conduct market research and the other firm's best response will be

not to conduct. Prescriptively then, our results tell a firm what it should do given what it expects its rival will do. This interpretation is consistent with the standard Nash equilibrium concept. Note that this feature is common in most product positioning models. For example, in Shaked and Sutton (1982) and in Moorthy (1988) one firm (arbitrarily denoted firm 1) selects a high-quality position and the other (arbitrarily denoted firm 2) selects a low-quality position in equilibrium. Asymmetric equilibria with ex ante symmetric firms is characteristic of games in other domains as well, e.g., in the context of selecting one of two pricing policies for selling cars (Desai and Purohit 2004) and in the context of selecting between uniform and targeted advertising (Iyer et al. 2005). In all these examples, identical firms make their decisions simultaneously and have equal opportunity sets, yet equilibria are sustained where each takes a different action. Relative to these models, the significance of the asymmetry in conducting market research is that the firms endogenously have different knowledge about the demand structure when making subsequent decisions, and that this asymmetry may or may not lead to a subsequent asymmetry in the innovation path selected (with implications for R&D levels as well). From an empirical standpoint, our asymmetric equilibria suggest that, under the appropriate conditions, we should observe heterogeneity in firm behavior with respect to market research, such as in the hiring of market research firms or in the allocation of funds and personnel to this activity.

One way the coordination issue of the asymmetric equilibrium can be explicitly modeled is by letting firms make sequential decisions. In an extension, we assumed that at $t = 1$ the first mover decides whether to conduct market research. After observing this decision, the second mover decides whether to conduct market research. We show that the unique asymmetric equilibrium is one where the first mover conducts market research, and its expected payoffs are greater than those of the second mover that forgoes market research; all other decisions are as in our basic setup. Of course, this kind of extension could still raise the issue of which firm goes first. But assuming any random process that prompts one firm to go first, our analysis would prescribe what the actions of the first and second mover should be. This also captures the notion that in some contexts it is uncommon for firms to make this decision at the same time.[21]

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[20] We thank Rick Staelin and participants of the SICS conference (2005) for proposing this extension to us.

[21] Asymmetric equilibria among identical players also arise in preemption and war of attrition games (see Fudenberg and Tirole 1991, on these types of games and the stability of asymmetric pure-strategy equilibria). We thank an anonymous reviewer for asking us to clarify these points.

5.3. Pursuing Multiple Innovations

Firms in our model were restricted to choosing one attribute to innovate on. In the model setup section, we justified scenarios where such an assumption is realistic (see footnote 3). We relaxed this assumption in the case of vertical preferences by allowing firms to pursue multiple innovations. Although firms would now select a positive R&D level to innovate on each attribute, our key findings continue to hold with respect to which attribute receives a greater R&D allocation. To see why, note that because an informed firm knows that the return will be higher, it has an incentive to select a higher R&D level for the attribute it discovers to be preferred by consumers (because it knows for sure the return on it is higher). Uncertainty avoidance is still relevant because an uninformed firm selects a higher R&D level for the safer attribute; the differentiation effect is still present under competition. Therefore, given that the same forces remain relevant for the R&D allocation decision, allowing firms to pursue multiple innovative routes complicates the exposition and analysis without offering much added insight.

5.4. Innovation on the Chosen Attribute Can Be Radical or Incremental

To capture technical uncertainty, we assumed that R&D is stochastic and that a firm's investment will have an impact on the probability of success. But the degree of improvement along the chosen attribute was fixed. We have examined a modification of the R&D structure in the vertical preferences case that allows firms to also determine the innovation level. Specifically, given the decision to innovate on attribute j, a firm can attempt either radical or incremental innovation on that attribute. The benefit to consumers would be V in the radical case and v in the incremental case ($V > v$) and the R&D cost factors would be K and γK ($\gamma < 1$), respectively. Hence, a radical innovation yields greater consumer benefits but is more difficult to develop with a given R&D budget. Our results show that the nature of the equilibria, in terms of whether to conduct market research and the choice of which attribute to attempt innovation on, identical to those of the model presented in the paper. Furthermore, if the incremental cost factor is not too small (i.e., γ close to 1), firms will always choose radical improvement. If, however, the incremental R&D cost factor is low enough, in all types of market research equilibria there exist conditions for firms to attempt different degrees of attribute improvement. For example, in the dual-market-research equilibrium both firms still choose to innovate on the preferred attribute, but one firm will attempt a radical improvement and the other an incremental improvement.

Thus, although the findings from this extension enrich the findings presented here, they do not alter them.[22]

5.5. Timeline of the Game

We assumed that in the first stage of the game ($t = 1$) firms make all their new product planning decisions: whether to conduct market research, which attribute to innovate on, and what R&D level to select. Several points are worth noting. First, in terms of the game played, this structure is the same as that where market research takes place in a separate, unobserved earlier stage (by definition of multistage games with unobservability; Fudenberg and Tirole 1991). Second, this structure presumes that market research takes little time compared with the product development cycle. Although this is true in many cases (where R&D can take years and market research only several months), in other cases the durations are more comparable. This is compounded by the fact that if a firm forgoes market research and begins development immediately, it may gain first mover advantages. In an extension, we analyzed a model that explicitly allows market research to take time. We show that all the equilibria (per Proposition 2) continue to hold, with two exceptions: (a) If the time it takes to conduct market research is in an intermediate range, then the single-market research equilibrium is unique when the monetary cost of market research is low; in some sense, getting to market later acts as an opportunity cost, and (b) if the disadvantage to a late mover is high enough, we can never sustain a dual-market-research equilibrium because one firm will always find it optimal to skip market research in the hopes of being first to market. Note also that in many real-world instances market research is indeed unobservable as assumed; i.e., it is difficult for a firm to verify whether its rival has conducted market research. Relaxing this assumption, so that market research is conducted in a first stage and the decision is known before the attribute and R&D level decisions are made, does not qualitatively affect the nature of our findings.

5.6. Cost Cutoffs Relative to Profits

The various equilibria of the model were characterized in terms of market research cost regions. Figure 1, for example, depicts these regions for the vertical preferences case. Because the reader may wonder how the cost cutoffs compare to the attainable rewards from innovation, we examine the single-market-research case. Table 1 illustrates the range

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[22] In addition to deciding on the degree of attribute innovation, in some cases firms may consider devoting R&D effort to reducing production costs. Given our focus on consumer preferences over the product attribute space, we have abstracted away from such process innovation. that is aimed at lowering variable costs.

Table 1 Single-Market-Research Cost Cutoffs as a Percentage of Maximal Attainable Profits

$\alpha =$	$K = 2V$ (%)		$K \to V$ (%)	
	$D = V/2$	$D = V$	$D = V/2$	$D = V$
0.5	19–28	33–56	11–22	19–48
0.4	16–27	28–54	9–21	16–48
0.25	10–16	19–34	6–12	10–31

(upper and lower cutoffs) for the single-market-research equilibrium to be unique as a percent of the highest possible rewards. The exact relative magnitudes depend on the model's parameters. For example, if the development cost is relatively low ($K \to V$), the degree of market uncertainty is moderate ($\alpha = 0.4$), and the disutility from the less preferred attribute is moderate ($D = V/2$), then if the cost of market research is just 9% of the maximal attainable profits one firm will forgo it.

As for actual market research cost for informing innovation decisions, these can run into hundreds of thousands, even millions, of dollars when one takes into account the multiple required components (interviews, focus groups, conjoint studies, etc.) and dedicated staff to analyze the data and form recommendations. In addition, the time required can often slow product development, which has both opportunity cost and late-mover disadvantage implications. Griffin and Hauser (1993) discuss these issues and how in some instances product development teams are unwilling to bear the costs and delays. As noted earlier, we analyze the time-delay implications of market research in the Technical Appendix, available at http://mktsci.pubs.informs.org.

5.7. Limitations

We believe our model captures many of the important issues firms face in setting innovation strategy under market uncertainty and a number of extensions have been examined. Nonetheless, we acknowledge several limitations of our study and discuss them in turn.

To focus on the incentives to conduct market research and invest in R&D, we assumed no differences across firms in the ability to undertake either of these activities. Our approach has been to show that asymmetric equilibria can arise even if we restrict attention to identical firms with equal competencies. In reality, asymmetries in firms' abilities may exist, and may be linked to differences in their industry position. These could affect the findings presented by exogenously creating greater or lower incentives to undertake market research or R&D.

The nature of consumer demand for innovation in our model along with standard Bertrand competition implied that a firm is never better off when its rival's R&D efforts succeed (see profits in Lemmas 1 and 4).

Hence, R&D investments in our model were never strategic complements. Indeed, our demand and price markup functions are consistent with the broad conditions in Athey and Schmutzler (2001) such that investments are strategic substitutes in the vertical preferences case and in the horizontal preferences case when firms target the same segment.[23] However, one could envision situations where a rival's introduction of a similar innovation serves to boost the firm's own profits. This can happen if multiple new products increase primary demand or speed up adoption (e.g., by reducing consumer apprehension or by increasing the amount of advertising that creates awareness for the category), or if network externalities are relevant and compatible competing products result in a greater customer base and higher consumer WTP (Conner 1995, Sun et al. 2004). If such factors are present, they could lead to strategic complementarity of R&D investments. One would need a different demand and product market competition structure than in our model to accommodate these factors. How these issues would relate to incentives to resolve market uncertainty and the innovation path firms select, which is the focus of our research, is not immediately obvious and would require further examination that is beyond the scope of this paper.

Last, we have made several assumptions about the market uncertainty firms face and how it can be resolved through market research. First, we assume that firms know the potentially relevant attributes or features but are uncertain either about their relative importance to consumers or how many consumers care about each one. In practice, discovering the relevant attributes may itself require some form of early market research (such as talking to retailers or observing consumers; see Srinivasan et al. 1997).[24] Second, for simplicity, market research was modeled as a binary decision that provides perfect information about consumer preferences for innovation on the relevant attributes. This captures many real-life situations where the nature of the study or consulting project needed for a reliable market forecast is known and a decision on whether to commission

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[23] Specifically, see Lemma 1 in Athey and Schmutzler (2001, p. 6), which is relevant for what they term "incremental investment" games. We note that if there is a disparity among firms, and one firm has no stand-alone incentive to innovate (Katz and Shapiro 1987), i.e., it would only be cannibalizing current sales by innovating, then R&D investments could be strategic complements for that firm.

[24] It seems straightforward to extend our model to a situation where only one attribute (say, "b") is known ex ante as potentially relevant for consumers, while another attribute (with probability α) may be discovered through market research to matter for consumers. If a firm forgoes market research it can only attempt innovation on attribute b because it knows what the other attribute is.

such a study must be made at the outset. It can also be interpreted as a decision to set up a substantial marketing arm in the new product planning phase.[25] Although market research techniques keep improving, and increasingly provide firms with accurate information about consumer preferences, in some instances accuracy may be limited. Separate analysis we conducted revealed that if one holds the cost of market research constant but lets the precision of the information vary, we can sustain the following equilibria. Market research is conducted by: (a) both firms, if it is very precise; (b) neither firm, if it is very imprecise; and (c) only one firm for mid-levels of precision. In the case of mid-level precision, because the informed firm does not entirely trust the findings it may prefer to differentiate rather than attempt innovation on the attribute that the (noisy) market research indicates is more valued. Third, we assumed that a firm that forgoes market research and successfully completes new product development will know the true demand at launch. Thus, any price adjustment period is relatively short. In reality, a firm that skipped upfront research may find that test marketing prior to launch can improve commercial performance (Crawford and Di Benedetto 2005). However, at that stage it is typically not possible to change the characteristics of the innovation, which is the focus of our paper.

6. Conclusion and Managerial Implications

Setting the course for new product development is a critical managerial decision in a range of industries. In making this decision, firms need to take into account the inherent demand and technology uncertainties along with competitive pressures. A recent business practice is to establish a separate organizational entity, often called the New Product Planning group, which tries to integrate assessments of market potential, estimates of R&D feasibility, and anticipation of rival actions (Ofek 2006). In this paper, we have attempted to shed light on how firms behave in such a context by examining the front-end incentives to undertake market research (that resolves demand uncertainty) and the factors that influence the selection of R&D level (that reduces technical uncertainty)—all of which feed into the formulation of innovation strategy in the face of competition.

In Figure 4, we provide a summary of our main findings by indicating what actions a firm should take given the current market and competitive conditions. We highlight the main managerial implications. First, when the cost of market research is nonnegligible (intermediate), a firm should not rush to conduct such research. Basically, if rivals are expected to undertake market research, this has the effect of lowering the value of information about consumer preferences and the best course of action could be to forgo market research. For example, if the rival is expected to commence serious negotiations with a market research firm or to begin hiring a number of market research professionals, the firm should consider forgoing such efforts if they are relatively costly.[26] Second, about the decision on which attribute to pursue and the R&D level to set, we find that the recommended course of action depends on the nature of the market uncertainty. If firms are uncertain as to which attribute is more important for all consumers (vertical case)—e.g., whether consumers care more about laptop weight or about convenience and performance—then a firm that conducts market research should always pursue the attribute it discovers is more valued. Because in this case, market information directs a firm's R&D to the more profitable attribute, it increases the incentives to invest. A firm that conducts market research should be the most aggressive in R&D investment when its rival forgoes such upfront research. When it is prohibitively costly to conduct market research, firms should be very mindful of the development challenges. If technical uncertainty is fairly low and R&D is likely to succeed, a firm should select a different innovation path than its rival.

If the type of market uncertainty firms face relates to the size of segments, each primarily interested in innovation on one of the attributes (horizontal case). For example, what fraction of patients need greater efficacy in treating acute depression versus others for which cotreating physical pain is lacking with existing drugs? In this case, a firm that conducts market research may act counter to information indicating which innovation the majority of consumers care about. In particular, if the rival chooses the attribute that turns out to appeal to the larger segment, a firm may consciously opt for a niche strategy to avoid head-to-head competition and, as a result, should invest lightly in R&D. Of course, if the niche segment is discovered to be too small, the firm should attempt innovation for the much larger segment. If the rival

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[25] These characterizations are consistent with our examples. In the case of laptops, Compaq was given the proposal for the number of focus groups to run and the cost. Management had to decide whether to conduct them or go with the development path perceived as safer (Bell and Leamon 1999). In the case of antidepressants, Eli Lilly decided to dedicate a team of market researchers to evaluate the new drug opportunities (Ofek 2006).

[26] This can also be interpreted in a sequential-move setup, where the second mover knows what the first mover decided about market research. In this case (see the discussion in §5), the first mover may find it beneficial to preempt and conduct market research because its profits will be higher than those of the second mover who will forgo market research if the costs are high enough.

Figure 4   Summary of Main Findings: Implications for Firm Behavior
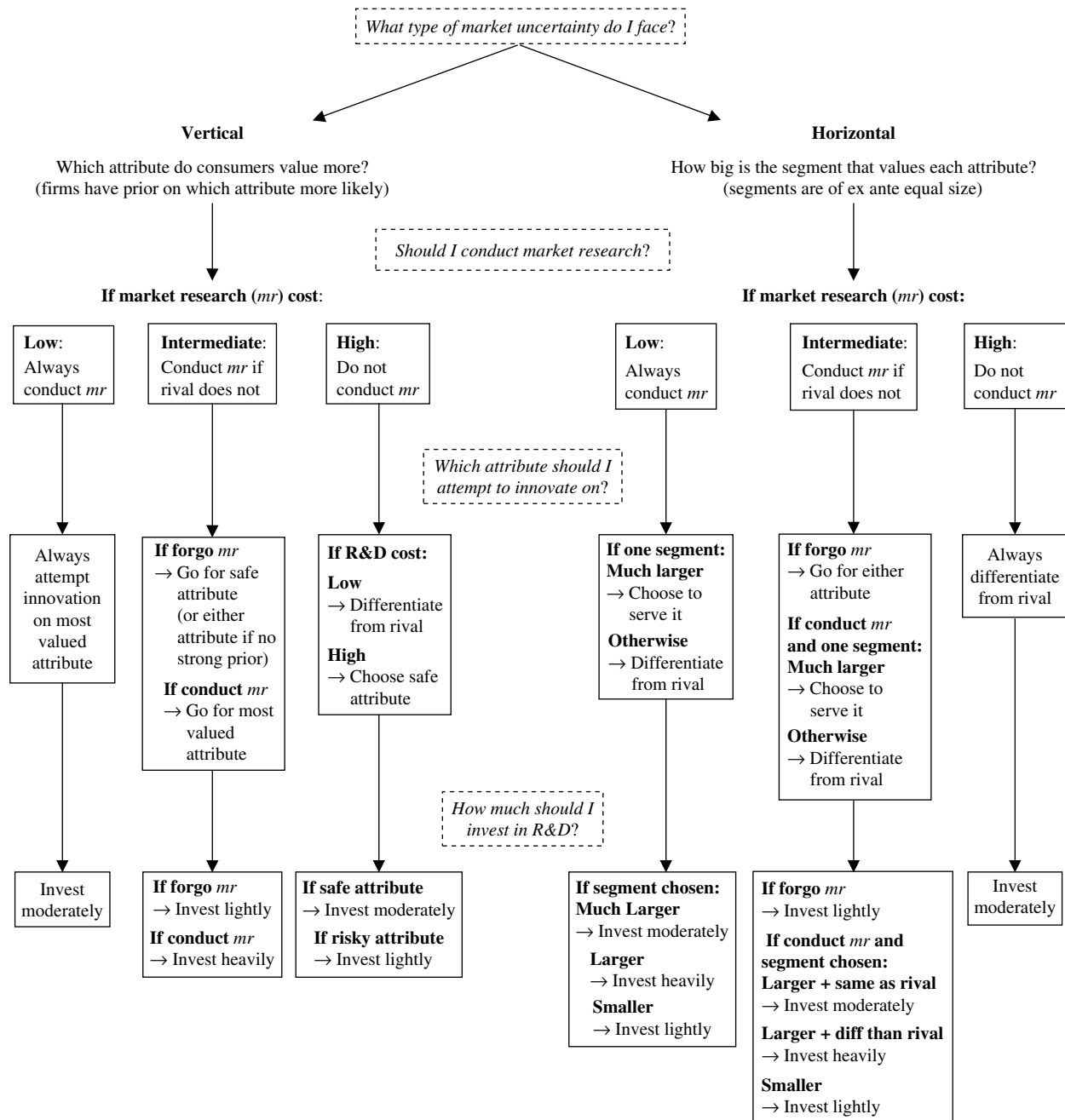
also conducted market research and will hence also be targeting this segment, then R&D should be set moderately.

At an industry level, our work is relevant for understanding certain patterns of evolution. For example, when firms forgo costly market research we can expect distinct innovation paths to be selected more often. This can occur even if one path is initially perceived as more likely to achieve market acceptance than the other. Although we have purposefully focused on ex ante symmetric firms, one could imagine sit-

uations where incumbents are better positioned to preempt the safer innovation route, particularly if it is of a sustaining nature (Christensen 1997).[27] This might help explain why changes in industry leadership often take place through entrant innovation of dimensions that incumbents initially dismissed or that

[27] For instance, incumbents may be better positioned from the R&D capability standpoint to pursue a sustaining path, or the rewards to a sustaining path can be higher for incumbents because of reputation in that domain.

industry experts touted as being less likely to matter to consumers.

These implications lend themselves to several empirically testable propositions. When all firms forgo market research, they are inclined to choose different innovation paths. So, first we should expect, on average, a negative correlation between the amount of market research conducted in an industry and the variance in the type of innovations pursued. Second, because differentiation matters more when products are easier to develop, we should expect a negative correlation between the cost of R&D and the variance in the type of innovations pursued. Third, because firms tend to act similarly in terms of conducting market research at low and high costs, but differently at intermediate levels, we should expect a nonlinear (U-shaped) relationship between the degree of correlation of their expenditures on market research and the cost of the research. To test these propositions, ideally one would like to have information on market research spending at the new product planning phase. Survey instruments have proven very effective in NPD settings for eliciting relevant data. Note that it would probably suffice to know what kind of studies were conducted, how many dedicated personnel were put in charge, and how long it took. In many instances it will suffice to know whether a market research team was put in place. It is further possible to track which new products firms attempted to develop (through a survey, archival data, company press releases, or even knowing ex post which innovations were actually launched). R&D cost factors are typically a known quantity in a given industry or can be estimated based on past product development efforts and reported R&D levels (see, e.g., Mansfield et al. 1981, Mansfield 1987).

Acknowledgments

Appendix

PROOF OF LEMMA 1. Let firm i successfully innovate on attribute j. If firm i is a monopolist, i.e., the only firm introducing a new product, its optimal price is $p^m(i) = V$ if j is the preferred attribute, and $p^m(i) = V - D$ otherwise. When both firms introduce a new product, Bertrand price competition implies that firm i prices above zero only when j is the preferred attribute and the rival firm innovated on attribute $j' \neq j$, in which case $p^d(i) = D$. Otherwise, when both firms

sell nondifferentiated new products, the equilibrium price is $p^d(i) = 0$. Last, when firm i offers a new product that is inferior in the eyes of customers, the rival with a superior new product prices at D, which forces firm i to price at $p^d(i) = 0$. Profits follow these prices given that demand is normalized to 1.

PROOF OF LEMMA 2. Fix the R&D intensities of the firms in the interval $[0, 1)$. Recall that we denote by $j = c$ the choice to innovate on the preferred attribute, and by $j = \bar{c}$ the choice to innovate on the less preferred attribute. If a firm conducts market research then, conditional on the success of its R&D effort at $t = 2$, it can be (i) A monopolist, in which case choosing $j = c$ leads to profits of $V > V - D$, which are the profits it would get by choosing $j = \bar{c}$. (ii) A duopolist with a rival that innovates on the preferred attribute. Regardless of whether $c = a$ or b, the informed firm will get zero profits. (iii) A duopolist with a rival that innovates on the less favored attribute. In that case choosing $j = c$ leads to profits of $D > 0$, which are the profits it would get by choosing $j = \bar{c}$. Hence,

$$E\pi(i)[j = c \mid \varphi(i), \varphi(i')] > E\pi(i)[j = \bar{c} \mid \varphi(i), \varphi(i')]$$

$$\Rightarrow \max_{\varphi(i)} E\pi(i)[j = c \mid \varphi(i')] \geq \max_{\varphi(i)} E\pi(i)[j = \bar{c} \mid \varphi(i')]$$

$$\Rightarrow j = c \text{ is a dominant strategy.}$$

PROOF OF PROPOSITION 1. From Lemma 2, an informed monopolist innovates on the preferred attribute and maximizes $\varphi V - (K/2)\varphi^2$, which leads to $\varphi_c = V/K$ and $\pi_c^m = V^2/2K - C$. An uninformed monopolist that chooses to innovate on the safer attribute maximizes $\varphi_b(V - \alpha D) - (K/2)\varphi_b^2$, which leads to $\varphi_b = (V - \alpha D)/K$ and $\pi_b^m = (V - \alpha D)^2/2K$. An uninformed monopolist never innovates on attribute a because $\pi_a^m = (V - (1 - \alpha)D)^2/2K < \pi_b^m$ ($\forall \alpha < \frac{1}{2}$). Hence, a monopolist chooses $mr = 1$ iff $\pi_c^m \geqslant \pi_b^m$, or $C \leq C^m = V^2/2K - (V - \alpha D)^2/2K$. Because success probabilities satisfy $\varphi_j \in [0, 1)$, we require $V < K$.

PROOF OF PROPOSITION 2. Using the equilibrium of the $t = 2$ subgame (Lemma 1), we now characterize the equilibrium in remaining strategies $\sigma(i) = \{mr = \{0, 1\}, j = \{a, b\}, \varphi_j(i)\}$. In equilibrium, each firm's strategy must form a best response to its rival's strategy, denoted $\sigma(i') = \{mr' = \{0, 1\}, j' = \{a, b\}, \varphi_j(i')\}$. When a firm conducts market research, its attribute choice will depend on what it learned from market research $j(c)$.

Case 1. Rival strategy is $\sigma(i') = \{mr' = 0, j' = b, \varphi_j(i') = \varphi_b\}$. Firm i's best response is determined by comparing the expected profits from each of the following strategies:

(i) $\sigma(i) = \{mr = 0, j = b, \varphi_b(i) = \varphi\}$

$$\Rightarrow \pi(i) = \max_\varphi \varphi(1 - \varphi_b)(V - \alpha D) - \frac{K}{2}\varphi^2$$

$$= \frac{((1 - \varphi_b)(V - \alpha D))^2}{2K}.$$

(ii) $\sigma(i) = \{mr = 0, j = a, \varphi_a(i) = \varphi\}$

$$\Rightarrow \pi(i) = \max_\varphi \varphi[(1 - \varphi_b)(V - (1 - \alpha)D) + \varphi_b \alpha D] - \frac{K}{2}\varphi^2$$

$$= \frac{((1 - \varphi_b)(V - (1 - \alpha)D) + \varphi_b \alpha D)^2}{2K}.$$

(iii) $\sigma(i) = \{mr = 1, j = c, \varphi_c(i) = \hat{\varphi}_a$ if $c = a, \varphi_c(i) = \hat{\varphi}_b$ if $c = b\}$

$\Rightarrow \pi(i) = -C + (1-\alpha) \max_{\hat{\varphi}_b} \{\hat{\varphi}_b(1-\varphi_b)V - (K/2)\hat{\varphi}_b^2\}$

$\qquad + \alpha \max_{\hat{\varphi}_a} \{\hat{\varphi}_a[(1-\varphi_b)V + \varphi_b D] - (K/2)\hat{\varphi}_a^2\}$

$\qquad = -C + \dfrac{(1-\alpha)((1-\varphi_b)V)^2 + \alpha((1-\varphi_b)V + \varphi_b D)^2}{2K}.$

Case 2. Rival strategy is $\sigma(i') = \{mr' = 0, j' = a, \varphi_j(i') = \varphi_a\}$. Firm i's best response is determined by comparing the expected profits from each of the following strategies:

(i) $\sigma(i) = \{mr = 0, j = b, \varphi_b(i) = \varphi\}$

$\Rightarrow \pi(i) = \max_{\varphi} \varphi[(1-\varphi_a)(V - \alpha D) + \varphi_a(1-\alpha)D] - \dfrac{K}{2}\varphi^2$

$\qquad = \dfrac{((1-\varphi_a)(V - \alpha D) + \varphi_a(1-\alpha)D)^2}{2K}.$

(ii) $\sigma(i) = \{mr = 0, j = a, \varphi_a(i) = \varphi\}$

$\Rightarrow \pi(i) = \max_{\varphi} \varphi(1-\varphi_a)(V - (1-\alpha)D) - \dfrac{K}{2}\varphi^2$

$\qquad = \dfrac{((1-\varphi_a)(V - (1-\alpha)D))^2}{2K}.$

(iii) $\sigma(i) = \{mr = 1, j = c, \varphi_c(i) = \hat{\varphi}_a$

$\qquad$ if $c = a, \varphi_c(i) = \hat{\varphi}_b$ if $c = b\}$

$\Rightarrow \pi(i) = -C + (1-\alpha)$

$\qquad \cdot \max_{\hat{\varphi}_b} \left\{\hat{\varphi}_b[(1-\varphi_a)V + \varphi_a D] - \dfrac{K}{2}a\hat{\varphi}_b^2\right\}$

$\qquad + \alpha \max_{\hat{\varphi}_a} \left\{\hat{\varphi}_a(1-\varphi_a)V - \dfrac{K}{2}\hat{\varphi}_a^2\right\}$

$\qquad = -C + \dfrac{(1-\alpha)((1-\varphi_a)V + \varphi_a D)^2 + \alpha((1-\varphi_a)V)^2}{2K}.$

Case 3. Rival strategy is $\sigma(i') = \{mr' = 1, j' = c, \varphi_c(i') = \varphi_a$ if $c = a, \varphi_c(i') = \varphi_b$ if $c = b\}$. Firm i's best response is determined by comparing expected profits from each of the following strategies:

(i) $\sigma(i) = \{mr = 0, j = b, \varphi_b(i) = \varphi\}$

$\Rightarrow \pi(i) = \max_{\varphi} \varphi[(1-\alpha)(1-\varphi_b)V$

$\qquad\qquad + \alpha(1-\varphi_a)(V - D)] - \dfrac{K}{2}\varphi^2$

$\qquad = \dfrac{((1-\alpha)(1-\varphi_b)V + \alpha(1-\varphi_a)(V - D))^2}{2K}.$

(ii) $\sigma(i) = \{mr = 0, j = a, \varphi_a(i) = \varphi\}$

$\Rightarrow \pi(i) = \max_{\varphi} \varphi[\alpha(1-\varphi_a)V + (1-\alpha)$

$\qquad\qquad \cdot (1-\varphi_b)(V - D)] - \dfrac{K}{2}\varphi^2$

$\qquad = \dfrac{(\alpha(1-\varphi_a)V + (1-\alpha)(1-\varphi_b)(V - D))^2}{2K}.$

(iii) $\sigma(i) = \{mr = 1, j = c, \varphi_c(i) = \hat{\varphi}_a$

$\qquad$ if $c = a, \varphi_c(i) = \hat{\varphi}_b$ if $c = b\}$

$\Rightarrow \pi(i) = -C + (1-\alpha) \max_{\hat{\varphi}_b} \left\{\hat{\varphi}_b(1-\varphi_b)V - \dfrac{K}{2}\hat{\varphi}_b^2\right\}$

$\qquad + \alpha \max_{\hat{\varphi}_a} \left\{\hat{\varphi}_a(1-\varphi_a)V - \dfrac{K}{2}\hat{\varphi}_a^2\right\}$

$\qquad = -C + \dfrac{(1-\alpha)((1-\varphi_b)V)^2 + \alpha((1-\varphi_a)V)^2}{2K}.$

A strategy profile σ^* will be part of a perfect Bayesian Nash equilibrium of the game if for $i = \{1, 2\}$ we have $\pi(i)[\sigma^*(i), \sigma^*(i')] \geq \pi(i)[\hat{\sigma}(i), \sigma^*(i')]$, $\forall \hat{\sigma}(i)$, $i \neq i'$ (where $\hat{\sigma}(i)$ is any alternative strategy firm i can select). Using the profit levels established in the previous three cases, we can specify the conditions required for each equilibrium to hold.

No-market-research equilibrium, both firms choose attribute b. The R&D intensity of both firms is $\varphi_{bb}^{00} = (1 - \varphi_{bb}^{00})(V - \alpha D)/K \Longleftrightarrow \varphi_{bb}^{00} = (V - \alpha D)/(K + V - \alpha D)$. The two conditions for this equilibrium are derived by establishing when the profits in Case 1(i) are greater than those in Cases 1(ii) and 1(iii), respectively.

1. $\varphi_{bb}^{00} \leq \dfrac{1-2\alpha}{1-\alpha} \iff \dfrac{\alpha(V - \alpha D)}{1-2\alpha} \leq K.$

2. $C \geq C_{bb}^{00} = \dfrac{1}{2K}\Big((1-\alpha)((1-\varphi_{bb}^{00})V)^2 + \alpha((1-\varphi_{bb}^{00})V + \varphi_b^{00}D)^2$

$\qquad\qquad - ((1-\varphi_{bb}^{00})(V - \alpha D))^2\Big).$

No-market-research equilibrium, one firm chooses attribute a and the other b. The R&D intensities are $\varphi_{ab}^{00} = (K(V - (1-\alpha)D) - (V - D)(V - \alpha D))/(K^2 - (V - D)^2)$, $\varphi_{ba}^{00} = (K(V - \alpha D) - (V - D)(V - (1-\alpha)D))/(K^2 - (V - D)^2)$. Note that $\varphi_{ab}^{00} < \varphi_{ba}^{00}$. The two conditions for this equilibrium are derived by establishing when the profits in Case 1(ii) are greater than those in Cases 1(i) and 1(iii) and when the profits in Case 2(i) are greater than those in Case 2(iii). The profits in Case 2(ii) are always smaller than those in Case 2(i).

1. $\varphi_{ba}^{00} \geq \dfrac{1-2\alpha}{1-\alpha}.$

2. $C \geq C_{asym}^{00} = \max\{C_{ab}^{00}, C_{ba}^{00}\},$ where

$C_{ab}^{00} = \dfrac{1}{2K}\Big((1-\alpha)((1-\varphi_{ba}^{00})V)^2 + \alpha((1-\varphi_{ba}^{00})V + \varphi_{ba}^{00}D)^2$

$\qquad\qquad - ((1-\varphi_{ba}^{00})(V - (1-\alpha)D) + \varphi_{ba}^{00}\alpha D)^2\Big),$

$C_{ba}^{00} = \dfrac{1}{2K}\Big((1-\alpha)((1-\varphi_{ab}^{00})V + \varphi_{ab}^{00}D)^2 + \alpha((1-\varphi_{ab}^{00})V)^2$

$\qquad\qquad - ((1-\varphi_{ab}^{00})(V - \alpha D) + \varphi_{ab}^{00}(1-\alpha)D)^2\Big).$

Dual-market-research equilibrium. The R&D intensities satisfy $\varphi_{aa}^{11} = \varphi_{bb}^{11} = \varphi_{cc}^{11}$, and solve $\varphi_{cc}^{11} = (1 - \varphi_{cc}^{11})V/K \Leftrightarrow \varphi_{cc}^{11} = V/(V + K)$. The condition for this equilibrium is derived by establishing when the profits in Case 3(iii) are greater than those in Case 3(i). Because we have $\varphi_{aa}^{11} = \varphi_{bb}^{11}$, the profits in Case 3(i) are always greater than those in Case 3(ii).

1. $C \leq C^{11} = \dfrac{((1-\varphi_{cc}^{11})V)^2 - ((1-\varphi_{cc}^{11})(V - \alpha D))^2}{2K}.$

Single-market-research equilibrium, uninformed firm chooses attribute b**.** The R&D intensities are $\varphi_{bc}^{01} = ((K - V)(V - \alpha D))/(K^2 - (1 - \alpha)V^2 - \alpha(V - D)^2)$, $\varphi_{bb}^{10} = (1 - \varphi_{bc}^{01})V/K$, $\varphi_{ab}^{10} = ((1 - \varphi_{bc}^{01})V + \varphi_{bc}^{01}D)/K$. Note that $\varphi_{bb}^{10} < \varphi_{ab}^{10}$. The two conditions for this equilibrium are derived by establishing when the profits in Case 1(iii) are greater than those in Cases 1(i) and 1(ii) and when the profits in Case 3(i) are greater than those in Case 3(iii). The profits in Case 3(i) are greater than those in Case 3(ii) given that $\varphi_{bb}^{10} < \varphi_{ab}^{10}$.

1. $C \geq C_{bc}^{01} = \dfrac{1}{2K}\big((1-\alpha)((1-\varphi_{bb}^{10})V)^2 + \alpha((1-\varphi_{ab}^{10})V)^2$
$ - ((1-\alpha)(1-\varphi_{bb}^{10})V + \alpha(1-\varphi_{ab}^{10})(V-D))^2\big).$

2. $C \leq C_{cb}^{10} = \min\{C_{bb}^{10}, C_{ab}^{10}\},$

where

$$C_{bb}^{10} = \frac{1}{2K}\big((1-\alpha)((1-\varphi_{bc}^{01})V)^2 + \alpha((1-\varphi_{bc}^{01})V + \varphi_{bc}^{01}D)^2$$
$$- ((1-\varphi_{bc}^{01})(V-\alpha D))^2\big),$$

$$C_{ab}^{10} = \frac{1}{2K}\big((1-\alpha)((1-\varphi_{bc}^{01})V)^2 + \alpha((1-\varphi_{bc}^{01})V + \varphi_{bc}^{01}D)^2$$
$$- ((1-\varphi_{bc}^{01})(V - (1-\alpha)D) + \varphi_{bc}^{01}\alpha D)^2\big).$$

Note that when $C_{cb}^{10} = C_{bb}^{10} \Longleftrightarrow \varphi_{bc}^{01} \leq (1-2\alpha)/(1-\alpha)$.

Single-market-research equilibrium, uninformed firm chooses attribute a**.** The R&D intensities are $\varphi_{ac}^{01} = ((K - V)(V - (1-\alpha)D))/(K^2 - \alpha V^2 - (1-\alpha)(V-D)^2)$, $\varphi_{aa}^{10} = (1 - \varphi_{ac}^{01})V/K$, $\varphi_{ba}^{10} = ((1 - \varphi_{ac}^{01})V + \varphi_{ac}^{01}D)/K$. Note that $\varphi_{aa}^{10} \leq \varphi_{ba}^{10}$. The three conditions for this equilibrium are derived by establishing when the profits in Case 2(iii) are greater than those in Case 2(i) and when the profits in Case 3(ii) are greater than those in Cases 3(i) and 3(iii). The profits in Case 2(i) are always greater than those in Case 2(ii).

1. $\alpha \geq \dfrac{1-\varphi_{ba}^{10}}{2-\varphi_{aa}^{10}-\varphi_{ba}^{10}}.$

2. $C \geq C_{ac}^{01} = \dfrac{1}{2K}\big((1-\alpha)((1-\varphi_{ba}^{10})V)^2 + \alpha((1-\varphi_{aa}^{10})V)^2$
$ - (\alpha(1-\varphi_{aa}^{10})V + (1-\alpha)(1-\varphi_{ba}^{10})(V-D))^2\big).$

3. $C \leq C_{ba}^{10} = \dfrac{1}{2K}\big((1-\alpha)((1-\varphi_{ac}^{01})V + \varphi_{ac}^{01}D)^2 + \alpha((1-\varphi_{ac}^{01})V)^2$
$ - ((1-\varphi_{ac}^{01})(V-\alpha D) + \varphi_{ac}^{01}(1-\alpha)D)^2\big).$

To conclude the proof, let $(C^{01}, C^{10}) = (C_{bc}^{01}, C_{cb}^{10})$ if the equilibrium $\binom{01}{ac}$ does not exist, and $= \{\min(C_{bc}^{01}, C_{ac}^{01}), \min(C_{cb}^{10}, C_{ca}^{10})\}$ otherwise. Moreover, let $C^{00} = C_{bb}^{00}$ if the equilibrium $\binom{00}{ab}$ does not exist, $= C_{ab}^{00}$ if equilibrium $\binom{00}{bb}$ does not exist, and $= \min(C_{bb}^{00}, C_{ab}^{00})$ otherwise. Then from the expressions in the various conditions of the proof we derive $0 < C^{01} < C^{11} < C^{10} < C^{00}$.

Proof of Result 1. From the proof of Proposition 2: Condition 1 of the no-market-research equilibrium with $j = j' = b$ requires $K \geq \underline{K}$ where $\underline{K} = \max(V, \alpha(V-\alpha D)/(1-2\alpha))$. Condition 1 of the no-market-research equilibrium with $j \neq j'$ requires

$$\frac{K(V-\alpha D) - (V-D)(V-(1-\alpha)D)}{K^2 - (V-D)^2} \geq \frac{1-2\alpha}{1-\alpha}$$
$$\Leftrightarrow 0 \geq K^2 - (V-D)^2$$
$$- \frac{1-\alpha}{1-2\alpha}\big(K(V-\alpha D) - (V-D)(V-(1-\alpha)D)\big).$$

Note that this parabola in K has a root greater than $V - D$ and a root smaller than $V - D$. Call K_1 the greater root. K_1 can be larger or smaller than V ($K_1 = V$ when $\alpha = 0$ and $K_1 > V$ when $\alpha = \frac{1}{2}$). Hence, the existence of this equilibrium requires $K \leq \bar{K}$ where $\bar{K} = \max(V, K_1)$. It follows from the definitions that $\underline{K} \leq \bar{K}$ and that, as a function of α, both first equal V and then increase with an infinite limit at $\alpha = \frac{1}{2}$.

Proof of Result 2. The first part follows directly from $C_{bc}^{01} < C_{cb}^{10}$. For the second part of the result, we need to compare the expected profit expressions of Case 3(ii) to those of Case 3(i) in Proposition 2. The sustainability of this equilibrium thus requires $\alpha V^2 + (1-\alpha)(V-D)^2 + (V - (1-\alpha)D)/(1-2\alpha)(\alpha V - (1-\alpha)(V-D)) \geq K^2$, which is not satisfied for $\alpha = 0$ but is for $\alpha = \frac{1}{2}$. As the left-hand side is an increasing function of α, there must exist an $\bar{\alpha}$ as stated in the result.

Proof of Lemma 3. Using the expected profit expressions from the proof of Proposition 2, we have $\partial^2 \pi(i)/\partial\varphi(i)\partial\varphi(i') < 0$ for all R&D intensities.

Proof of Proposition 3. Ranking the R&D levels follows from a comparison of the equilibrium R&D expressions derived in the proof of Proposition 2. This involves tedious algebra, and the details are available from the authors. The value of α^* is found by solving the condition for $\varphi_{ba}^{11} > \varphi_{cc}^{11} \Leftrightarrow (K/D)(V^2 - (V-D)^2)/((V+K) \cdot (K + (V-D))) = \alpha^* > \alpha$. Note that when $K \to V$, $\alpha^* \to \frac{1}{2}$. Therefore, there is a nonempty range of K and V values for which the no-market-research equilibrium with one firm choosing attribute a exists for large C and the dual-market-research equilibrium exists for small C and $\varphi_{ba}^{00} > \varphi_{cc}^{11}$. Table A.1 gives the comparative statics that arise from differentiating each R&D level by the model's parameters.

Proof of Lemma 4. If firm i innovates successfully on attribute j and its rival does not, firm i sells to all the consumers of its segment at price V. Its profits are $s_b V$ if $j = b$ and $(1 - s_b)V$ if $j = a$. If both firms introduce new products with innovation on the same attribute, profits are zero because of Bertrand competition. If a firm fails to innovate (its R&D fails), its profits are zero as well.

Proof of Proposition 4. An informed monopolist always attempts innovation on the attribute that appeals to the larger segment and maximizes $\varphi \max\{s_b, 1 - s_b\}V - (K/2)\varphi^2$, which leads to $\varphi_c = \max\{s_b, 1 - s_b\}V/K$; hence the expected payoffs from conducting market research are $\pi_c^m = E[\max\{s_b, 1 - s_b\}]^2 V^2/2K - C$. An uninformed monopolist attempts innovation on either of the two attributes and maximizes $\varphi(V/2) - (K/2)\varphi^2$, which leads to $\varphi_j = \frac{1}{2}(V/K)$ and $\pi_j^m = (V/2)^2/2K$.

Table A.1   Comparative Statics for R&D Levels

	φ_{ac}^{01}	φ_{bc}^{01}	φ_{ab}^{00}	φ_{bb}^{00}	φ_{ba}^{00}	φ_{cc}^{11}	φ_{bb}^{10}	φ_{aa}^{10}	φ_{ab}^{10}	φ_{ba}^{10}
α	+	−	+	−	−	0	+	−	+	−
D	−	−	−	−	+ then −[c]	0	+	+	+	+
V	+ then −[a]	+ then −[a]	+ then −[b]	+	+		+	+	+	+
K	+ then −	+ then −	+ then −[c]	−	−		−	−	−	−

Notes. "+" means R&D level is increasing in the parameter, "−" means R&D level is decreasing in the parameter. Footnotes (a)–(c) give conditions for a nonlinear relationship, increasing and then decreasing.

[a] If α small or (K/D) large, − otherwise; [b] if α small, + otherwise; [c] if α small, − otherwise.

PROOF OF PROPOSITION 5.

No-market-research equilibrium, one firm chooses attribute a and the other b. The R&D intensities are $\varphi_{ab}^{00} = \varphi_{ba}^{00} = V/2K \equiv \varphi^{00}$. The equilibrium is sustainable only if neither firm can earn greater profits by deviating and engaging in market research, leading to the condition:

1. $C \geq C_s^{00} = \int_0^{1/(2-\varphi^{00})} \frac{((1-s_b)V)^2}{2K} f(s_b)\, ds_b$

$+ \int_{1/(2-\varphi^{00})}^1 \frac{((1-\varphi^{00})s_b V)^2}{2K} f(s_b)\, ds_b - \frac{V^2}{8K}.$

Dual-market-research equilibrium. We use the notation introduced in Result 3. In the proposed equilibrium, when $s_b < 1 - \bar{s}_b$ or $\bar{s}_b < s_b$, both firms target the larger segment c, in which case they will set $\varphi_{cc}^{11} = s_c V/(K + s_c V)$. When $1 - \underline{s}_b < s_b < \underline{s}_b$, the firms target different segments, one targets the larger segment c in which case it sets $\varphi_{c\bar{c}}^{11} = s_c V/K$, and the other targets the smaller segment $\bar{c}$ in which case it sets $\varphi_{\bar{c}c}^{11} = (1 - s_c)V/K$. When $1 - \bar{s}_b \leq s_b \leq 1 - \underline{s}_b$ or $\underline{s}_b \leq s_b \leq \bar{s}_b$, both equilibria are sustainable. Let $\{j'(s_b), \varphi'(s_b)\}$ be the strategy of a firm in a dual-market-equilibrium. We have $\{j'(s_b), \varphi'(s_b)\} = (c, \varphi_{cc}^{11})$ if $\bar{s}_b < s_c$, $= (c, \varphi_{c\bar{c}}^{11})$ or $(\bar{c}, \varphi_{\bar{c}c}^{11})$ if $\frac{1}{2} \leq s_c < \underline{s}_b$, and $= (c, \varphi_{cc}^{11})$ or $(c, \varphi_{c\bar{c}}^{11})$ or $(\bar{c}, \varphi_{\bar{c}c}^{11})$ if $\underline{s}_b \leq s_c \leq \bar{s}_b$. This equilibrium exists only if neither firm can increase its profits by deviating and not engaging in market research, leading to the condition:

1. $C \leq C_s^{11}$

$= \max_{(j'(s_b), \varphi'(s_b))} \left\{ \begin{array}{l} \displaystyle\int_0^1 \max_{j(s_b), \varphi(s_b)} \pi(j(s_b), \varphi(s_b) \\ \displaystyle\mid j'(s_b), \varphi'(s_b))f(s_b)\, ds_b \\ \displaystyle - \max_{j, \varphi} \int_0^1 \pi(j, \varphi \mid j'(s_b), \varphi'(s_b))f(s_b)\, ds_b \end{array} \right\}.$

Single-market-research equilibrium, uninformed firm chooses attribute b.[28] The R&D intensity of the uninformed firm is $\varphi^{01} = (KV/2 - \int_{1/(2-\varphi^{01})}^1 s_b^2 V^2 f(s_b)\, ds_b)/(K^2 - \int_{1/(2-\varphi^{01})}^1 s_b^2 V^2 f(s_b)\, ds_b)$.[29] Define $\hat{s}_b = 1/(2 - \varphi^{01})$. In the proposed equilibrium, when $s_b \leq \frac{1}{2}$ the informed firm invests in attribute a in which case it sets $\varphi_{c\bar{c}}^{10} = (1-s_b)V/K$. When $\frac{1}{2} \leq s_b \leq \hat{s}_b$, the informed firm still invests in attribute a and sets $\varphi_{\bar{c}c}^{10} = (1-s_b)V/K$. When $\hat{s}_b \leq s_b$, the informed firm invests in attribute b and sets $\varphi_{cc}^{10} = (1-\varphi^{01})s_b V/K$. Let $(j^{10}(s_b), \varphi^{10}(s_b))$ be the R&D strategy of the informed firm in a single-market-research equilibrium. The two conditions for this equilibrium are derived by establishing when the informed firm cannot increase its expected profits by deviating and not engaging in market research, and the uninformed firm cannot increase its expected profits by deviating and engaging in market research.

1. $C \geq C_s^{01} = \int_0^1 \max_{j(s_b), \varphi(s_b)} \pi(j(s_b), \varphi(s_b) \mid j^{10}(s_b), \varphi^{10}(s_b))$

$\cdot f(s_b)\, ds_b - \frac{K}{2}(\varphi^{01})^2.$

[28] The single-market-research equilibrium where the uninformed firm chooses attribute a is derived by symmetry.

[29] The solution exists as the right-hand side is increasing in φ^{01} from a positive value to $V/2K < 1$.

2. $C \leq C_s^{10} = \int_0^{\hat{s}_b} \frac{(1-s_b)^2 V^2}{2K} f(s_b)\, ds_b$

$+ \int_{\hat{s}_b}^1 \frac{(1-\varphi^{01})^2 s_b^2 V^2}{2K} f(s_b)\, ds_b - \frac{(V/2)^2}{2K}.$

PROOF OF RESULT 3. If both firms choose to attempt innovation on attribute b in equilibrium, they invest $s_b V/(K + s_b V)$. One firm could deviate and invest $(1-s_b)V/K$ in attribute a. This deviation is not profitable iff $(1-s_b)V/K \leq s_b V/(K + s_b V) \Leftrightarrow 0 \leq s_b^2 V + s_b(2K - V) - K$. Hence, the condition $s_b \geq \underline{s}_b$, where $\underline{s}_b = (-K + \frac{1}{2}V + \frac{1}{2}\sqrt{4K^2 + V^2})/V$, is monotonically decreasing from $(\sqrt{5} - 1)/2$ to $\frac{1}{2}$ wrt K. The equilibrium with both firms attempting innovation on attribute a is derived by symmetry (note that we have $\underline{s}_a = \underline{s}_b = \underline{s}_c$). In an equilibrium where the firms choose different attributes, the optimal investment in attribute b is $s_b V/K$ and the optimal investment in attribute a is $(1-s_b)V/K$. The firm investing in a does not want to deviate to b iff $(1-s_b)V/K \geq (1 - s_b V/K)(s_b V/K) \Leftrightarrow s_b^2 V - 2Ks_b + K \geq 0$. Hence, the condition $s_b \leq \bar{s}_b$, where $\bar{s}_b = (K - \sqrt{K^2 - KV})/V$, is monotonically decreasing from 1 to $\frac{1}{2}$ wrt K. The nondeviation condition for the firm on attribute b is derived by symmetry. This yields the conditions in the result.

PROOF OF RESULT 4. If the uninformed firm invests $\varphi_{j'}$ in attribute j', the informed firm chooses between attribute j, with optimal R&D level $(1-s_{j'})V/K$, and attribute j', with optimal R&D level $(1 - \varphi_{j'})(s_{j'}V/K)$. The informed firm chooses j' iff $s_{j'} \geq 1/(2 - \varphi_{j'})$. Hence, if $j' = b$ then $\hat{s}_b = 1/(2 - \varphi_b)$, and if $j' = a$ then $\hat{s}_b = 1 - 1/(2 - \varphi_a)$.

PROOF OF RESULT 5. From the R&D expressions in Result 4, when the informed firm attempts innovation on a its R&D level is decreasing in s_b, and when it attempts innovation on b its R&D level is increasing in s_b. Result 3 shows that when $1 - \underline{s}_b < s_b < \underline{s}_b$, one firm attempts innovation on a (with R&D level $(1-s_b)V/K$) and the other b (with R&D level $s_b V/K$). So when s_b increases, these R&D levels will move in opposite directions.

PROOF OF LEMMA 5. From the R&D levels established in the proof of Proposition 5, when firms choose the same attribute we have $\partial^2 \pi(i)/\partial \varphi(i)\partial \varphi(i') < 0$, but when they choose different attributes $\partial \pi(i)/\partial \varphi(i') = 0$.

PROOF OF PROPOSITION 6. (i) We have $\varphi^{00} = V/2K = \int_0^1 sVf(s)\, ds/K > (\int_0^{\hat{s}_b} sVf(s)\, ds + \int_{\hat{s}_b}^1 (1 - \varphi_{cc}^{10}(s))sVf(s)\, ds)/K = \varphi^{01}$. (ii) We have $\varphi_{c\bar{c}}^{11} = \varphi_{c\bar{c}}^{10} = s_c V/K > (1 - \varphi^{01})s_c V/K = \varphi_{cc}^{10}$. We also have $\varphi_{cc}^{11} < \varphi_{cc}^{11} \Leftrightarrow (1 - s_c)V/K < s_c V/(K + s_c V) \Leftrightarrow s_c > \underline{s}_b$, where $\underline{s}_b$ is given in the proof of Result 3. (iii) $\varphi^{00} > \varphi_{cc}^{10} \Leftrightarrow V/2K > (1 - \varphi^{01})s_c V/K \Leftrightarrow 1/(2(1 - \varphi^{01})) > s_c$; hence, we can define the cutoff value $s_c^* = 1/(2(1 - \varphi^{01})) > \frac{1}{2}$, where φ^{01} is given in the proof of Proposition 5. Recall that for the informed firm to target the larger segment and set R&D level φ_{cc}^{10}, it must be the case that $s_c > \hat{s}_c = 1/(2 - \varphi^{01})$ (per the proof of Result 4). Thus we have $s_c^* > \hat{s}_c$; i.e., there is a nonempty region of segment sizes in which the informed firm in a single-market-research equilibrium chooses to innovate for the larger segment and sets a lower R&D level than each uninformed firm in a no-market-research equilibrium. Per the claim in Footnote 19, $\varphi^{00} > \varphi_{cc}^{11} \Leftrightarrow V/2K > s_c V/(K + s_c V) \Leftrightarrow s_c^{**} > s_c$, where we define $s_c^{**} = K/(2K - V) > s_c^*$. Per the proof of Result 3, $s_c^{**} > \underline{s}_c = (-K + \frac{1}{2}V + \frac{1}{2}\sqrt{4K^2 + V^2})/V \Leftrightarrow (1 + 1/(2K/V) - 1)^2 > 0,$

which is always true. Thus, a nonempty region of segment sizes exists in which each firm in a dual-market-research equilibrium innovates for the larger segment and sets a lower R&D level than each uninformed firm in a no-market-research equilibrium. Finally, note that $\varphi_{cc}^{11} < \varphi_{cc}^{10} \Leftrightarrow \varphi^{01} < \varphi_{cc}^{11}$ and φ_{cc}^{11} increases with respect to s_c. We checked that $\varphi^{01} < \min(\varphi_{cc}^{11}|_{s_b}, \varphi_{cc}^{11}|_{s_b})$ for a uniform distribution, as in this case φ^{01} solves $\varphi^{01} = V/2K - V^2/K^2(1-\varphi^{01})\frac{1}{3}(1 - 1/(2-\varphi^{01})^3)$.

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