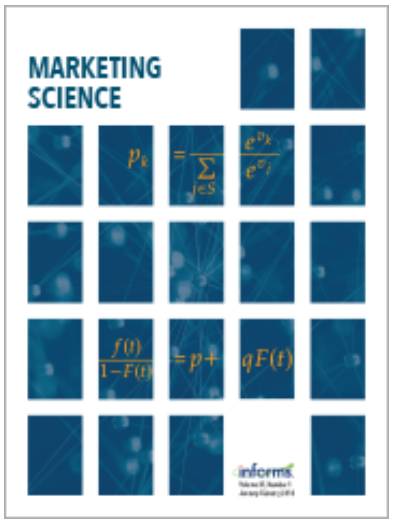

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The Strategic Impact of References in Business Markets

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We investigate a business-to-business context and ask *when* and *why* a firm should announce a "reference program" that commits the firm to facilitating the flow of information about the efficacy of its products from early adopters to potential late adopters. We model a monopolist manufacturer with a new innovation that can be sold to two potential customers. We demonstrate here two benefits of a reference program that relate not to an increase in later adopters' willingness to pay but to an increase in the willingness to pay of the early adopters themselves. The impact on the early adopters' willingness to pay arises in two ways as a result of their observation of the firm's commitment to information transmission. First, in a model of symmetric uncertainty, we show that the announcement of a reference program facilitates dynamic pricing by the manufacturer in the sense that it allows the firm to provide temporary exclusive use of the technology to one of the customers. This creates more value, which the manufacturer can extract via a higher price. In this way, a reference program can serve as a partial substitute for an exclusive-use contract. In a model with asymmetric information, we demonstrate that under certain conditions, the firm is able to use the reference program as a signal—again, to the early adopting customer—that its technology is of high quality. However, such a signal requires significant discounts to early adopters to ensure separation. As a result, a pooling equilibrium dominates in which the manufacturer fosters references regardless of its quality. Finally, by allowing the firms' private information to be stochastic, we show that separation may be a dominant outcome.

Key words: word of mouth; business-to-business marketing; game theory; signaling
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1. Introduction

It is very common in business-to-business (B2B) markets, particularly those in high-technology, for potential buyers to face significant uncertainty over a prospective purchase. This uncertainty may relate, for example, to the product's efficacy, the ultimate experienced value associated with product adoption, and the seller's commitment to providing service and support for the product. This necessarily leads to a decreased willingness to pay for the innovation as a result of lower expected values and higher risk premiums. Although firms in consumer markets often make use of free trials and/or moneyback guarantees to mitigate this uncertainty, such programs are often not as effective in B2B markets because of the sheer cost to the customer of testing and evaluating a new technology. One useful source of uncertainty reduction that does not require the buyer to invest significant resources is word-of-mouth (WOM) communication: later adopters learning from early adopters. For the selling firm, an obvious benefit of WOM—to the extent that it is positive—will be an increase in the awareness of, and/or willingness to pay for, the product. The positive impact of social interactions in this regard has been demonstrated empirically in a range of domains including television shows (Godes and Mayzlin 2004), movies (Liu 2006, Dellarocas et al. 2007), medical products (Manchanda et al. 2008, Iyengar et al. 2011, Zhang 2010),[1] technology products (Putsis et al. 1997), music (Salganik et al. 2006), books (Chevalier and Mayzlin 2006), restaurants (Godes and Mayzlin 2009, Wojnicki and Godes 2011), cellular phone service (Libai et al. 2009), and financial products (Duflo and Saez 2003).

Emerging from a recognition of the *importance* of social interactions has been increasing interest in the firm's role in proactively *managing* the flow of this information (Godes et al. 2005). In this paper, we study the strategic impact of a specific and common approach to the formal management of B2B WOM communication: *references*. In particular, we study the role played by references in B2B markets in which firms generate significant innovations characterized

[1] There is not necessarily consensus in the literature with respect to the impact of social interactions on the diffusion of pharmaceuticals. See, for example, Coleman et al. (1966) and Van den Bulte and Lilien (2001).

by high potential value for customers but also a high degree of uncertainty over whether such value will be realized. References occur when a prospective customer (a potential late adopter) is able to gather information from an existing customer (an early adopter) concerning the product's effectiveness and/or other nonobservable aspects of the value proposition.[2] The latter might include, for example, the firm's installation expertise or postsale service.

References are common in B2B markets and occur in both structured and unstructured ways. A casual search reveals that such well-known firms as IBM, Oracle, Microsoft, and Hitachi all maintain active formal "reference programs."[3] According to a survey of major technology firms including Hewlett-Packard, EMC, Fujitsu, Intel, and Siebel, 41% of companies have formal reference programs (Phelon Group 2005). It also appears that such programs are becoming more common because the same survey reported that more than half of the programs were less than three years old. A typical reference program consists of the centralized management of reference relationships in which the marketing organization recruits customers to become members of the program. Salespeople and other members of the marketing organization are then provided access to these references for use, for example, in closing deals, recruiting speakers for conferences, and producing advertisements featuring satisfied customers. The most common and basic of the activities a firm asks of a reference is the participation in a one-on-one conversation with prospective buyers at other firms.

It is also quite common for referencing activity to be connected to buyers' participation in other programs—early adopter programs, for example—in which these customers are granted early access to the innovative technology. As described on its early adopter program website, for example, Oracle notes that, among other things, "Customers get . . . advanced insight, earlier access and knowledge transfer," whereas "Oracle expect[s] . . . participation in marketing and reference activities" (OHUG 2011). Indeed, many other firms have programs offering a similar quid pro quo. In a list of the "best ideas in customer reference management" in 2009, an industry expert included a program "to recruit key customer references into product upgrade launches, provide them with incentives to adopt early, and then get them referencing about the upgrades quickly" (*Reference Point* 2010). It is important to note that this early access to technology may offer significant rewards for the early adopter. As described by Gomez-Arias and Montermoso (2007), for example, in exchange for providing a reference, Sony was able to gain a meaningful competitive advantage via its early access to EnterpriseDB's open source database.

The question we address is *when* and, especially, *why* a firm should announce a "reference program." Such a program is a commitment by the firm to foster the transmission of information from early adopters to prospective late adopters. Our model captures a number of the important idiosyncrasies associated with business markets. In particular, it accounts for the fact that firms often sell to customers who compete with one another. One implication of this is that a manufacturer introducing a new product has the choice of providing the exclusive use of the technology to one customer for a period of time. This may allow the customer to create additional value in his market that the manufacturer, in turn, can appropriate. Another important element of our model is customer-level pricing, a common aspect of business markets where firms often negotiate prices that allow them to extract value associated with the specific customer's situation. As we demonstrate, the benefits of customer-level pricing extend even to a context in which customers are completely ex ante homogeneous.

With respect to the benefits of a reference program, it is clear that ceteris paribus an increase in the prospect's willingness to pay—as a result of a positive reference from an early adopter—would be beneficial to the firm. However, we demonstrate here two additional benefits of this formalized information transmission that may be less obvious in that they relate not to an increase in the later adopters' willingness to pay but to an increase in the willingness to pay by the early adopters themselves, those implementing the word-of-mouth communication. The impact on the early adopters' willingness to pay may arise in two ways as a result of their observation of the firm's commitment to the information transmission. First, in a model of symmetric uncertainty, we show that the announcement of a reference program facilitates dynamic pricing by the manufacturer in the sense that it allows the firm to commit to selling to one customer in the first period and another customer in the second period. This may create more value for the first customer, which the firm can extract via a higher price. Thus, even when the firm may not contractually promise one customer exclusive use—for legal reasons, perhaps, or because contracting is

[2] It is important in this sense to distinguish *references* from *referrals* in that the latter more typically refer to information about a customer who might be a good prospect for the firm. References, on the other hand, convey information about the product and the firm itself to prospective customers. For an analysis of the organizational aspects of referrals, see Garicano and Santos (2004).

[3] See, respectively, http://www.ibm.com/ibm/clientreference/us/en, http://www.oracle.com/customers/gcp/customer-references.html, http://www.microsoft.com/hk/sia/default.mspx, and http://www.hds.com/customers/reference-program, all last accessed on August 6, 2009.

costly—the firm's adoption of a reference program may allow it to make such a commitment credibly. The intuition behind this result is that by committing to the transmission of information from the early adopter to the late adopter, the firm increases its expected profits from waiting until the second period to sell to a competing firm. In this way, *a reference program can serve as a partial substitute for an exclusive-use contract*.

We then extend the model to a context with asymmetric information in which the firm knows better than the customer the efficacy of its new technology. In such a context, we demonstrate that under certain conditions, the firm may be able to use the reference program as a signal—again, to the early adopters—that the technology is of high quality. However, this result is not as straightforward as it may appear. One would expect that lesser-quality firms should prefer not to facilitate the flow of unfavorable information. We show, however, that this separating equilibrium may be *dominated by a pooling equilibrium in which all firms announce that they will foster references regardless of their product quality.* In such an equilibrium, of course, the existence of a reference program provides no information to the early adopters. This occurs because the reference itself is inherently informative; it is equally informative to later adopters as would be a decision not to adopt a reference program. Thus, whether or not the lesser-quality firm adopts the reference program, it will earn low profits from later customers. Its adoption of the reference program, however, allows it to earn profits from early adopters who would remain uncertain about the technology. To address this, the high-quality firm may attempt to make the reference program costly by offering discounts to early adopters. However, the discounts necessary for separation can be onerous, and the high-quality firm may prefer to simply pool with the low-quality firm. Finally, in an extension, we show that when the firm has imperfect information about its type, there exists a nondominated separating equilibrium in which only high-quality firms facilitate references. Thus, in this model, we are able to show that a reference program allows the firm to earn higher revenue from early adopters via its use as a signaling mechanism.

The rest of this paper proceeds as follows. After reviewing the related literature in §2, we investigate in §3 the impact of a reference program in a symmetric information model. We demonstrate that such a program can serve as a commitment to one customer that the firm will not sell to its competitor in the short term. Thus, the program may serve as a partial substitute for an exclusive-use contract. In an effort to provide a parsimonious analysis, we have relegated all the analysis associated with robustness checks and extensions to this model to the electronic companion (at http://mktsci.journal.informs.org/), but we do discuss these results in §3.3. In §4, we endow the firm with private information about the efficacy of the technology it has developed and ask whether the reference program can credibly signal this information. Finally, the paper concludes in §5 with a discussion of the results, the limitations inherent in our approach, and directions for future research.

2. Related Literature

Our analysis here relates to a number of recent papers that have addressed the firm's management of social interactions. Mayzlin (2006) demonstrates that, in equilibrium, the firm's manipulation of consumer word of mouth—by, for example, secretly hiring people to spread positive news about its product—does not necessarily result in the destruction of the credibility typically associated with word-of-mouth communication. This result is based on the idea that good products have enough true word of mouth in the market that a randomly chosen message is still likely to be honest. Thus, people continue to believe what they hear even though, in equilibrium, firms with lower-quality products are disproportionately motivated to manipulate conversations. Dellarocas (2006) also studies the manipulation of consumer word of mouth and finds that firms may be locked into a prisoner's dilemma with respect to this manipulation. Although manipulation is *en toto* bad for the industry, if a firm chooses not to manipulate, the perception of its product will be harmed. As a solution to this problem, the author proposes the implementation of technologies to increase the cost of manipulation. A critical distinction between the present work and this stream of research is that we focus on the information inherent in the *announcement* of an observable word-of-mouth management program. As a result, our analysis relates to the impact these programs have on the initial adopters of innovations compared with the willingness of the customers to share their experiences with later adopters. Moreover, we focus here on the firm's role in facilitating the transmission of *truthful* information compared with the manipulation of customers via the transmission of false, or misleading, information.

Recent research has addressed programs designed to encourage satisfied customers to tell others about their experiences. Biyalogorsky et al. (2001) investigate whether and when incentives for such endorsements should be used compared with some other less direct approach, such as lower prices. Verlegh et al. (2004) raise questions about a rational customer's response to such recommendations. Nonetheless, research suggests that such programs

may be effective. Ryu and Feick (2007) demonstrate empirically that incentives can be effective in encouraging people to share their experiences. Godes and Mayzlin (2009) present both field and lab data that show that firm-driven recommendations may, in some cases, have a meaningful impact on sales. As mentioned above, our focus in this study differs from this stream in that we investigate the impact on early adopters of the firm's commitment to fostering their recommendations. In some sense, although this stream of work has presumed the benefits of word of mouth and has focused on how to foster it, we study here whether and why the benefits exist and make the assumption that the firm is able to foster the recommendations should it want to do so.

Finally, a third related stream of theoretical work has looked at the firm's role with respect to online reviews. Chen and Xie (2005) investigate the firm's optimal response to the arrival of exogenous customer reviews. Specifically, they demonstrate that it is not always in the firm's interest to include references to positive reviews in its advertising content. This is because such an approach may result in harmful price competition from rivals. Chen and Xie (2008) extend their analysis to consider the firm's proactive management of consumer reviews. They show that allowing customers to post their reviews on the firm's site is only beneficial to the extent that these reviews are sufficiently informative. Moreover, they demonstrate that such reviews are most valuable when there are many novice users. The context addressed in these papers—online reviews—is primarily consumer oriented. In contrast, we study the firm's management of personal interactions between its customers. This distinction between the consumer and B2B contexts is important in a number of ways, including the potential for competition among customers and negotiated pricing. By modeling these characteristics explicitly, we are able to demonstrate benefits to the firm as a result of early adopters' observation of its commitment to fostering word-of-mouth communication.[4]

3. Model Setup: Symmetric Information

The context we capture in our model is a high-technology B2B market. We focus on a monopolist[5] that has produced an innovative technology around which there exists significant uncertainty. In an extension, we demonstrate that this context is isomorphic to one with duopolists, one of which has a superior, innovative technology. The firm has two potential customers. The technology "works" ($\theta = \overline{\theta}$) with probability p and does not work ($\theta = \underline{\theta}$) with probability $1 - p$. Nature chooses the technology's efficacy θ at the outset of the game and reveals it to neither the manufacturer nor the customers. The technology is durable such that the customer will reap its benefits for all periods following its purchase; if the customer purchases in period 1, it has use of the technology for two periods. If it purchases in period 2, it has use of the technology for only one period.

Each customer i is ex ante identical and earns equilibrium monetary profit of

$$\pi_i = \begin{cases} \pi_{00} & \text{if } \theta = \underline{\theta}, \\ \pi_{w(i)\times w(-i)} & \text{if } \theta = \overline{\theta}, \end{cases} \tag{1}$$

where $w(j) \in \{0, 1\}$ represents firm $j's$ adoption decision. So $w(i) = 0$ (1) implies that firm i adopted (did not), and $w(-i)$ captures the adoption decision of firm i's competitor. Thus, π_{10}, for example, represents the profits a firm earns when it purchases an effective technology while its competitor does not, whereas π_{01} are the profits when the firm does not purchase the technology but its competitor does, etc. As implied in (1), the customer is assumed to be as equally well-off if he had not purchased the technology as he would be with a technology that does not work. The impact of relaxing this assumption is assessed in an extension. Note that π_i does not include the price paid for the technology. We assume the following ordering of profits:

$$\pi_{10} \geq \pi_{11} \geq \pi_{00} \geq \pi_{01}. \tag{2}$$

Conditional on $\theta = \overline{\theta}$, firms are better off having the technology than not and worse off if their competitor has it.[6] We assume that π_i captures all important information about the technology. The technology may offer the firm a demand-side benefit, such as

[4] It is worth noting that the firm's use of references is not limited to the facilitation of one-on-one conversations between prospects and customers. For example, it is also common for customer testimonials to be featured on vendors' websites or in advertisements. In this way, references can also represent a novel form of "content" for use in traditional marketing channels. As we discuss in §5, this may represent an interesting and fruitful avenue for future research.

[5] As discussed by Shugan (2002), a monopoly model, although less realistic in some cases, may be preferable to a competitive model. In addition to the often significant complexity one must navigate, the latter often requires strong assumptions regarding the optimal decisions of all players. Because our model is characterized by a unique, innovative technology, it would seem to capture well the author's conclusion that "perhaps the primary purpose of marketing is the creation and creative use of monopoly power" (Shugan 2002, p. 227). It is on the latter point that the current paper is focused.

[6] The ordering in (2) precludes contexts in which a customer is better off when his competitor has access to a technology. This might arise, for example, when competitive promotion raises awareness levels of a new innovation above that which would result from a single firm's promotion. Of course, in such a setting, the manufacturer would not seek to endow a firm with exclusive use.

an improvement in the firm's value proposition, or a supply-side benefit, which might take the form of a variable cost reduction. The assumption that $\pi_{11} \geq \pi_{00}$ is meant to capture the idea that, in equilibrium, the manufacturer will not profit from welfare-decreasing innovations. In fact, as will be shown, it is a condition of the focal equilibrium in this section that this inequality be strict. Note also that these quantities allow us to assess the impact of competition on the results. This will be captured by the differences $\pi_{11} - \pi_{10}$ and $\pi_{01} - \pi_{00}$, which capture the impact on firm i's profits of firm $-i$'s adoption of the technology.

In a given period, each customer makes decisions simultaneously about when and whether to acquire the manufacturer's technology if it is offered. Given the existence of uncertainty, we allow for the possibility that customers are risk averse. As is standard, we capture this via a utility function $u(z)$ associated with the monetary payoff z such that $u' > 0$ and $u'' \leq 0$. Note, of course, that risk neutrality in which $u(z) = z$ is nested in this specification. The manufacturer is risk neutral by assumption; we relax this assumption in an extension. Our approach here is similar to the standard assumption in the agency theory literature that the principal is risk neutral while the agent is risk averse. In our model, the manufacturer is creating its policy with respect to reference programs and pricing. This, one would assume, would be done optimally and without regard for risk, which the firm's owners can diversify. On the other hand, purchasers of the technology are making decisions that may involve idiosyncratic, individual risks to their careers, reputations, etc. Thus, it would seem reasonable to see their choices as being made under risk aversion.

Where it is necessary to distinguish them, we refer to the two customers as A and B. Reflecting the institutional characteristics of most business-to-business markets, the manufacturer chooses customer-specific prices P^A and P^B at which to sell the technology to each of the customers. Each price P^i is a take-it-or-leave-it offer and is observable only by customer i. Thus, a contract between the manufacturer and customer A cannot be contingent on the price between the manufacturer and customer B. We make the assumption that customer arrival is endogenous in that the manufacturer decides *when* to sell to each customer. Because there are two customers, the firm may choose to sell to both in period 1 or to sell to them sequentially over two periods. For simplicity of exposition, we assume that there is no discounting of future profits. Qualitatively equivalent results can be derived with a discount factor $\delta \in (0, 1)$ as long as δ is not too low. There are no variable costs associated with selling the technology so the manufacturer's profits are $\Pi = P^A + P^B$.

Finally, we assume that customers receive their profits from both periods only at the end of the game, after period 2. One might interpret this as a delay between actual performance and any learning that might occur as a result of that performance. We impose this assumption to ensure that the only source of firm i's learning about the efficacy of the technology, if it does not acquire the technology in period 1, is through a reference from customer $-i$. That is, the assumption precludes inferences by a nonpurchasing firm about the technology by inspecting their own profits. Although such learning surely does occur, in reality the firm- or division-level profit is an aggregation of many shocks, the specific level and nature of which are often difficult to discern with accuracy. We investigate the relaxation of this assumption in an extension.

3.1. Exclusive Use

In choosing when (indeed, if) to sell to each customer, the manufacturer rationally prefers to maximize the potential value created by the innovation for customers because, ceteris paribus, the more value that is created, the more that will be available to be captured. It is well known that monopoly profits commonly far exceed duopoly profits. See, for example, Salant et al. (1983) for an analysis of this issue within the context of a Cournot setup. These authors show that the merger of any number of firms into a single monopolist yields higher profits than the sum of the individual firms' profits. Applying this concept to our model here suggests that exclusive use may lead to far higher profits for the manufacturer's customers than would nonexclusive use; i.e., $\pi_{10} \gg \pi_{11}$. If this were true, the manufacturer would prefer to sell the technology to only a single firm, endowing this customer with a "monopoly" over the technology. As long as the customer views the claim of exclusive use as credible, the manufacturer will be in a position to capture the value associated with this exclusive use via a high price.

Our central focus is on the credibility of the claim of exclusive use. Our main result below states that a reference program can endow such a claim with credibility. To focus on this mechanism, we make the assumption that other possible sources of commitment—in particular, contracts—are unavailable or are not entirely effective.[7] This assumption—that the firm is unable to perfectly commit to an action—is a common one. Scholars have studied important strategic problems under a similar assumption of noncommitment, ranging from compensation (Freixas et al. 1985) to taxation (Benhabib and

[7] Of course, in reality, these mechanisms are likely to work in concert.

Rustichini 1997) to marketing research (Lauga and Ofek 2009). Indeed, the fundamental motivating force behind the entire signaling literature is that the firm is unable to either contract on or otherwise commit to honest revelation of its "type."

There are a number of reasons why the access to, or enforceability of, an exclusive-use contract may be limited. On one hand, it is technically illegal in the United States and many other nations to limit the competitive intensity between firms in a market. A particularly important case in the common law that has addressed this topic is *Jefferson Parish Hospital v. Hyde*, in which the decision includes the following test for anticompetitive behavior:

> Exclusive dealing can have adverse economic consequences by allowing one supplier of goods or services unreasonably to deprive other suppliers of a market for their goods, or by allowing one buyer of goods unreasonably to deprive other buyers of a needed source of supply. In determining whether an exclusive-dealing contract is unreasonable, the proper focus is on the structure of the market for the products or services in question—the number of sellers and buyers in the market, the volume of their business, and the ease with which buyers and sellers can redirect their purchases or sales to others. Exclusive dealing is an unreasonable restraint on trade only when a significant fraction of buyers or sellers are frozen out of a market by the exclusive deal.[8]

In practice, a common standard employed is that at least 30% of buyers or sellers must be foreclosed from access to either supply or demand for the exclusive dealing to be considered problematic and potentially illegal. Of course, it is rare that the enforceability of contracts is known perfectly ex ante. Therefore, even when there is a question as to whether or not such a contract would "hold up" in court, firms may be willing to enter into them. However, the buyer is likely to discount the value it attaches to exclusive use in the face of this uncertainty. Even when such a contractual agreement is reached, there are reasons to believe that the buyer will not be fully confident that he will retain monopoly rights throughout its term. One potential limitation in this regard may be the imperfect observability by competing firms of each other's technological investments. Imagine, for example, that a manufacturer were to write a contract with customer A, specifying that the latter would have sole use of its technology for a period of time. It would be rational for customer A to be concerned, nonetheless, that if the manufacturer were to sell to customer B—A's direct competitor—in violation of its promise, this may go unnoticed.

[8] *Jefferson Parish Hospital Dist. v. Hyde*, 466 U.S. 2. 1984. Accessed August 5, 2009, http://supreme.justia.com/us/466/2/case.html.

Finally, there is a rich literature in a variety of domains on the costliness of contracting (Crocker and Reynolds 1993; Wernerfelt 1997, 2007; Bajari and Tadelis 2001). This cost reflects the difficulty the parties may face in specifying precisely the various contingencies that could unfold over the life of the contract as well as assigning the rights and responsibilities to each party should these contingencies arise. One important implication of these bargaining costs is that most contracts are necessarily incomplete. For our purposes here, this implies that the parties would rationally be uncertain as to what their returns will be at the conclusion of the two-period game even if they had written an exclusive-use contract. As a result, customer A—even upon receiving a contractual promise that the manufacturer will not sell the technology to its competitor—rationally discounts this promise somewhat and is thus not willing to pay to the manufacturer the value he would be willing to pay if he were unambiguously and credibly promised exclusive use of the technology. Thus, the manufacturer may benefit from a mechanism that could serve to increase the credibility of its promise.

We demonstrate in the following sections that a reference program may in some cases perform the role of communicating the firm's commitment to (temporary) exclusive use. Such a program thus allows the firm to capture more of the value its technology may create because it makes exclusive use of the technology incentive compatible: no contract is needed. As a result, the customer granted exclusive use (i.e., the early adopter) is not uncertain about whether the contract will be honored or enforced.[9]

3.2. Model Analysis

We investigate the firm's choice of selling format. The simplest case is the simultaneous sale, where

[9] Our analysis does not consider the potential legal actions taken by customers who are not given exclusive use. One might imagine that these firms could claim harm by the exclusive use of the product by their competitors. Two comments are in order in this regard. First, as will be shown in our main result, the later adopter is not excluded from the market entirely in our reference equilibrium. Indeed, it is critical for this result that the later adopter is informed about quality via a reference program and then purchases the product, albeit later than the early adopter. Thus, in some sense, there is likely to be less harm than would be the case under an exclusive-use contract, which would last longer. Second, one may also argue that in our model the later adopter realizes a benefit over the early adopter in that it learns about the efficacy of the technology via the reference before adopting it. Although we do not consider such a context in our formal modeling, it is plausible that customers who are more risk averse would prefer to be the recipient—rather than the generator—of the reference. Thus, we would expect that the potential for legal action would be lower under the reference program-based exclusivity compared with a contract-based exclusivity.

the manufacturer sells to both customers in the first period. In this format, neither firm is granted exclusive use, and both make their purchases under uncertainty, captured by the parameter p. Both the competition among the customers and the technological uncertainty reduce the surplus available to the manufacturer, making this a potentially unattractive format in some cases.

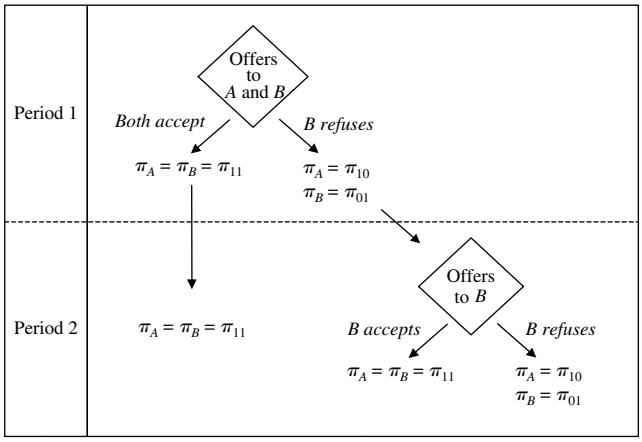
For the reasons argued above, the manufacturer may want to sell the technology to just one customer, allowing this customer to reap the benefits associated with being the "monopoly user" of the technology for the entire duration of the game. This should create higher rents for the customer and, thus, the manufacturer. Nonetheless, it is straightforward to demonstrate that, in our model, such a format is not implementable: there exists no equilibrium in which the firm—in the absence of a contract or another commitment device—is able to credibly claim that a customer will maintain exclusive use throughout both periods. As discussed in more depth in the electronic companion, the manufacturer will always find it profitable to deviate from this equilibrium. As a solution, we show in §3.2.2 that the manufacturer may choose to implement a selling format in which it fosters the transfer of information about the technology to the second firm. That is, it can enlist the first firm to serve as a "reference" for the technology. In this format, the second customer is able to purchase the technology without uncertainty about its efficacy.

3.2.1. Simultaneous Sale Format. In the simultaneous sale (SS) format, the manufacturer sells to both customers in the first period. No information transfer occurs, so each customer buys based on their expectations associated with the technology. Figure 1[10] provides a graphical representation of the timing and stages of the game, including both on- and off-path actions. Following nature's choice of the technology's efficacy, the manufacturer makes a take-it-or-leave-it offer of price P_{SS} at which each customer can acquire the technology. If a customer deviates from the equilibrium path by refusing to purchase in period 1, the other firm is offered exclusive use, and the deviating firm must wait until period 2 to purchase. We solve this subgame by seeking a subgame-perfect Nash equilibrium in prices, conditional on the firm's choice of selling format SS.

The manufacturer offers price P_{SS} to both customers in period 1. This price must, in equilibrium, satisfy the following implicit equation:

[10] For clarity of exposition, Figure 1 presents only a partial picture of the game. In particular, note that customer profits here are conditional on $\theta = \bar{\theta}$, and we do not show what happens when both firms refuse (in which case neither firm acquires the technology until the firms are offered it again in period 2).

Figure 1 Timing of the SS Format: Profits Conditional on $\theta = \bar{\theta}$



$$\begin{aligned} &pu(\pi_{11} - P_{SS}) + (1-p)u(\pi_{00} - P_{SS}) \\ &\quad + [pu(\pi_{11}) + (1-p)u(\pi_{00})] \\ &= pu(\pi_{01}) + (1-p)(\pi_{00}) \\ &\quad + [pu(\pi_{11} - P'_{SS}) + (1-p)u(\pi_{00} - P'_{SS})], \end{aligned} \tag{3}$$

where the equality captures the fact that the firm is able to extract all incremental expected utility associated with the technology. The left-hand side of (3) is the on-path expected utility available to each customer. Recall that the customer pays for the technology once, in the first period, and then experiences the benefits for both periods. The right-hand side captures the expected utility of the customer's outside option, which is to turn down the price P_{SS}. In the second period of such a deviation, the customer again receives a take-it-or-leave-it offer, this time of P'_{SS}, given by the following implicit equation:

$$\begin{aligned} &pu(\pi_{11} - P'_{SS}) + (1-p)u(\pi_{00} - P'_{SS}) \\ &\quad = pu(\pi_{01}) + (1-p)(\pi_{00}), \end{aligned} \tag{4}$$

since the customer's only outside option at this point is to allow his competitor to retain exclusive use. Substituting (4) into (3) yields

$$\begin{aligned} &pu(\pi_{11} - P_{SS}) + (1-p)u(\pi_{00} - P_{SS}) \\ &\quad + [pu(\pi_{11}) + (1-p)u(\pi_{00})] \\ &\quad = 2[pu(\pi_{01}) + (1-p)u(\pi_{00})], \end{aligned} \tag{5}$$

which uniquely characterizes P_{SS} and which is clearly increasing in π_{11} and decreasing in π_{01}. It is not a central result, but it is interesting to note that, in such an equilibrium, both customers are (weakly) worse off following the introduction of a new technology. This can be seen in (5) by the fact that $pu(\pi_{01}) + (1-p)(\pi_{00}) \leq u(\pi_{00})$ since $\pi_{01} \leq \pi_{00}$. This difference is

strict so long as $\pi_{01} < \pi_{00}$.[11] Intuitively, this is because the manufacturer is able to benefit from the competitive intensity between the firms. The purchase of the technology becomes a prisoner's dilemma in which the customers would both be better off in equilibrium if they could convince the manufacturer not to enter the market. However, they are each *individually* better off adopting in equilibrium regardless of the other's adoption decision since $\pi_{1\times w(-i)} > \pi_{0\times w(-i)}$.

3.2.2. Reference Format. In the reference (RF) format, firm A is offered exclusive use of the product in period 1 in exchange for an agreement to provide an honest reference in period 2 to customer B. We assume that between periods 1 and 2, both the manufacturer and customer A observe θ. Customer A then provides this information to customer B, and the manufacturer offers a price contingent on the realization of θ. We do not model any other obligation on behalf of firm A as part of this agreement. In particular, we do not consider the customer to be a "beta site" that would allow the manufacturer to improve the product before selling it to customer B. We exclude it from the model to isolate the effects of the referencing activity more precisely. We discuss an extension in §3.3 in which we allow customer A to assist in product improvement.

We stress that the assumption regarding honesty on behalf of customer A is consistent with rational equilibrium behavior because, given the model setup, customer A is indifferent between providing an honest reference and lying. This is the case because, although his profits are lower if customer B adopts an effective technology, his profits are not affected by P^B_{RF}, the price customer B pays for the technology: *firms are impacted by their competitors' technology adoption, not the price paid for the technology*. Because the manufacturer can always give the product away for free, it is clear that customer A's reference will impact only customer B's price but not his adoption decision.[12] Given this indifference, we thus focus on equilibria in which customer A's equilibrium strategy is to tell the truth.

We assume that there is no cost to the manufacturer to facilitate this referencing activity.[13] For simplicity, we make the assumption that the decision as to whether the firm will facilitate customer A's reference is not contingent on the realization of θ. That is, customer B will learn θ regardless of its value. We relax this assumption in an extension discussed in §3.3 and show that it is not a restrictive one. See Figure 2 for the sequence of actions in this format.

In period 2, when $\theta = \bar{\theta}$, the manufacturer makes a take-it-or-leave-it offer of P^B_{RF} that satisfies the following equality:

$$u(\pi_{11} - P^B_{\mathrm{RF}}(\bar{\theta})) = u(\pi_{01}).$$

The only option customer B has is to forgo the purchase of the technology and to allow its rival exclusive use of it for a second period. Thus, it is clear that

$$P^B_{\mathrm{RF}}(\bar{\theta}) = \pi_{11} - \pi_{01}. \tag{6}$$

The linearity of this price should not be surprising because there is no uncertainty facing customer B in the reference format. Finally, given the setup, it is clear that $P^B_{\mathrm{RF}}(\underline{\theta}) = 0$. As in the previous two formats analyzed, were customer A to turn down the offer, then customer B would be made the same offer. Given this setup, P^A_{RF} must satisfy the following equality:[14]

$$\begin{aligned} &pu(\pi_{10} - P^A_{\mathrm{RF}}) + (1-p)u(\pi_{00} - P^A_{\mathrm{RF}}) \\ &\quad + [pu(\pi_{11}) + (1-p)u(\pi_{00})] \\ &= pu(\pi_{01}) + (1-p)u(\pi_{00}) \\ &\quad + [pu(\pi_{11} - P^B_{\mathrm{RF}}) + (1-p)u(\pi_{00})], \end{aligned} \tag{7}$$

where we note that, off-path, the firm only pays $P^B_{\mathrm{RF}} > 0$ in period 2 with probability p. Using (6), we can rewrite (7) as follows:[15]

$$\begin{aligned} &pu(\pi_{10} - P^A_{\mathrm{RF}}) + (1-p)u(\pi_{00} - P^A_{\mathrm{RF}}) \\ &\quad + [pu(\pi_{11}) + (1-p)u(\pi_{00})] \\ &= 2[pu(\pi_{01}) + (1-p)u(\pi_{00})]. \end{aligned} \tag{8}$$

[11] Note that this result is not necessarily robust to alternative specifications of the allocation of value. Thus, if the customers were both in some sense "strong" and the manufacturer were "weak," such that the latter was not able to appropriate a significant proportion of the value associated with the innovation, then the customers would surely be better off following the introduction. Still, the result persists for a range of surplus-splitting assumptions and not simply for the manufacturer-take-all setting.

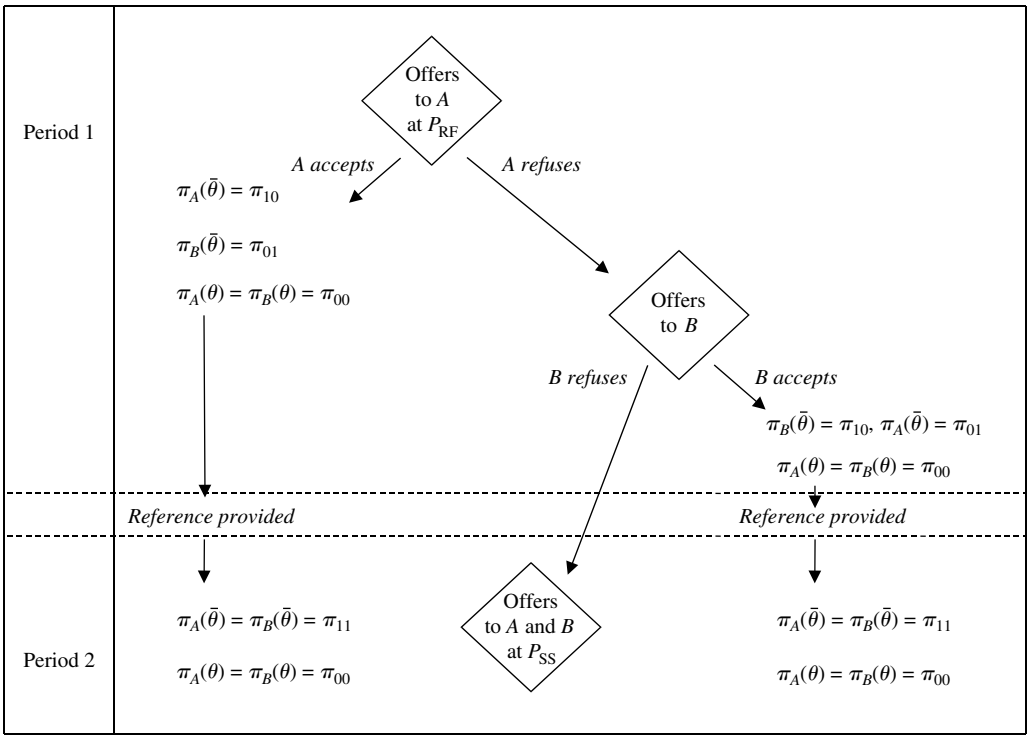
[12] In this core model setup, we require that the manufacturer faces no variable costs associated with the delivery and/or installation of the product at a zero price. If this were not true, customer A would be able to impact adoption. In an extension, we relax the profit specification, which allows us to demonstrate that as long as the low-quality technology's value is not too low relative to any variable costs that may exist, the result would still persist.

[13] According to the Phelon Group (2005), the hard costs to a manufacturer associated with administering such a program are not substantial. For example, for firms with annual sales between \$1 billion and \$5 billion, the average cost was \$100K–\$500K.

[14] We focus here on the customers' profit-level outcomes, but it is surely the case that there are other, nonprofit-related reasons to be a reference. These may include, for example, enhancing one's stature in the industry or expanding one's network. Given the generality of our setup, these benefits could easily be incorporated into π_{10} in the reference format to imply that the manufacturer would extract the value associated with these benefits as well.

[15] This expression demonstrates the complex factors driving the early adopter's price. It is thus difficult to state unambiguously whether the early or the late adopter pays a higher price. However, we can state that when p is low, early adopters will certainly pay a lower price. This can be seen by allowing $p \to 0$, which implies that, for any other parameter value, $P^A_{\mathrm{RF}} \to 0$.

Figure 2 Timing of Reference Format



The following proposition is our first main result that demonstrates that the reference format may allow the manufacturer to make a credible commitment to providing customer A with exclusive use in period 1. All proofs can be found in the appendix.

Proposition 1. *The firm's claim that it will offer customer A exclusive use in period* 1 *is credible iff* (a) *it writes a reference contract, and* (b) $P_{RF}^{B'} < pP_{RF}^{B}$, *where* $P_{RF}^{B} = \pi_{11} - \pi_{01}$ *and* $P_{RF}^{B'}$ *is defined uniquely by the following implicit equation*:

$$\begin{aligned} &pu(\pi_{11} - P_{RF}^{B'}) + (1-p)u(\pi_{00} - P_{RF}^{B'}) \\ &\quad + [pu(\pi_{11}) + (1-p)u(\pi_{00})] \\ &\quad = 2[pu(\pi_{01}) + (1-p)u(\pi_{00})]. \end{aligned} \tag{9}$$

Necessary conditions for credibility are (i) π_{11} *is high relative to* π_{00}, (ii) *the customer is not risk neutral, and* (iii) p *is not too high.*

Proposition 2. *The following are sufficient conditions to ensure that* $P_{RF}^{B'} < pP_{RF}^{B}$: (i) p *is low enough,* (ii) π_{01} *is close to* π_{00}, *and* (iii) $u'(\pi_{00})$ *is high enough.*

$P_{RF}^{B'}$ is the price the manufacturer would offer to customer B were it to deviate from the equilibrium and sell to B in the first period. Several comments are in order.[16] First, this does not yet demonstrate that the firm will optimally contract with customers for a reference. What we show here is that it is possible to commit to such a selling format, not that it is optimal to do so. We analyze below the relative profitability of the reference format compared with the simultaneous first-period sale of the technology to both customers. Second, we stress that *this credibility does not exist without the reference program*. Intuitively, the fact that customer A will tell customer B the value of θ creates enough of an expected gain for the manufacturer that the claim that it will wait until period 2 to sell to B is incentive compatible.[17]

The intuition behind the necessary conditions for this equilibrium is straightforward. To hold, the RF format requires that the technology will provide "enough" of a surplus improvement for its customers, which, in turn, sufficiently enhances the manufacturer's surplus. That is, the firms must earn sufficiently more with the technology than without it.

[16] Although the conditions in Propositions 1 and 2 are similar when stated in their qualitative form, they are not mathematically equivalent. Thus, we do not make the claim that they are both necessary and sufficient.

[17] The result is more general than it appears. First, it is not at all dependent on the assumption that the manufacturer has take-it-or-leave-it power and thus extracts all surplus. If, instead, we assumed that a proportion η of the available surplus went to the manufacturer and $1-\eta$ to each customer. Then all that would change would be that both the left- and right-hand sides of (9) would be multiplied by η. Similarly, our assumption that customers are homogeneous is not limiting. We could easily allow for customers A and B to have distinct utility functions (one may be more risk averse, for example). The impact of this would be simply that the equality in (9) would be stated in terms of customer B's utility function.

To understand the implications of this, imagine that this were not the case so that $\pi_{11} = \pi_{00}$. In essence, the trade-off faced by the manufacturer is the potential benefit associated with convincing customer B that $\theta = \bar{\theta}$ against the fact that this customer will only have use of the technology for one period. When $\pi_{11} \to \pi_{00}$, the former vanishes as the customer becomes less and less concerned about the differences in his payoffs under the two states of the world.

Analogous reasoning holds for condition (ii) in Proposition 1. Were the customer risk neutral, there would be no net expected gain in the customers' willingness to pay conditional on the information being made available. Finally, as the prior probability that the technology works approaches 1, the marginal benefit of waiting until the second period to find out whether it works and, if so, to extract more value declines. The manufacturer gets lower expected benefits from waiting, and thus its claim that it will do so is no longer credible.

As a final note, it is again the case here that both customers are strictly worse off following the introduction of a new technology. This is obvious from (8) since $\pi_{01} \leq \pi_{00}$. Whereas it is intuitive that in a model with a monopolist manufacturer the customers would not be able to retain any of the value associated with a new technology, it may be less obvious that they are, in fact, worse off. Again, this is a direct result of the prisoner's dilemma aspect of a new technology in the face of competing customers.

Our ability to fully characterize the equilibrium in Proposition 1 is limited somewhat by the general specification of the utility functions. As the following proposition shows, we can make a cleaner statement about the existence of a referencing equilibrium when we impose a specific functional form.

Proposition 3. *When* $u(z) \equiv -\exp(-rz)$, *where* r *is the coefficient of absolute risk aversion, as* $\pi_{01} \to \pi_{00}$, *there always exists a* $p' \in (0, 1)$ *such that there exists a subgame-perfect equilibrium of the RF game if and only if* $p < p'$.

This proposition demonstrates that, within the context of this commonly used utility specification, firms can use a reference program in order to implement the sequential sale of products when exclusive-use contracts are not an option as long as the probability of success is not too high. When there exists a high prior on the product's success, the manufacturer will always deviate and sell in the first period.

The following proposition completes our analysis of the core symmetric-information model by comparing the profits available to the firm from choosing the RF and SS formats and shows that, indeed, referencing is an equilibrium.

Proposition 4. *Whenever the firm's claim of exclusive use is credible, the following set of strategies represents a subgame-perfect equilibrium in the game*: (i) *the manufacturer adopts the RF format and offers prices* P^A_{RF}, *and either* $P^B_{\mathrm{RF}}(\bar{\theta}) = \pi_{11} - \pi_{01}$ *or* $P^B_{\mathrm{RF}}(\underline{\theta}) = 0$; *and* (ii) *customer A truthfully reveals to customer B the realization of* θ. *Moreover, when this equilibrium exists, it is the Pareto-dominant equilibrium in the model*.

This proposition follows from the fact that $P^A_{\mathrm{RF}} > P_{\mathrm{SS}}$ and that the existence of an equilibrium in the RF format implies that $pP^B_{\mathrm{RF}} > P^{B'}$. Thus, Propositions 4 and 1 demonstrate that a reference program may partially substitute for the firm's inability or unwillingness to contractually provide exclusive use to one of its customers even though it is profitable to do so. The reference program is only a *partial* substitute because the commitment to such a program requires the firm to sell to customer B in the second period. In this way, one can think of a reference program—more generally, the firm's attempts to foster the spread of word of mouth about its products—as a mechanism that provides information not only to those later adopters who benefit from the experiences of the early adopters but also to the early adopters themselves who can be ensured that they will have sole use of the technology for a period of time while the manufacturer waits for the later adopters to learn. This message allows the manufacturer to capture higher rents from the early adopters. Put differently, though we typically think of word of mouth as speeding up diffusion, our results here demonstrate that, on the contrary, such a commitment by the firm may serve as a signal that it will *slow down* the diffusion of its products.[18]

Returning to the examples at the outset of this paper, our results suggest that the link between early adopter programs, on one hand, and reference programs, on the other, may be more strategic than previously appreciated. Indeed, the results suggest that Oracle's requirement that firms participating in its program perform referencing activities enhances its ability to capture the value provided by the early and exclusive use of the technology. Similarly, these results suggest that the references provided by Sony in order to procure early and exclusive use of EnterpriseDB's product (Gomez-Arias and Montermoso 2007) not only helped the latter to sell its product to future customers but also may have allowed it to extract additional value from Sony: because Sony could only

[18] Though subgame perfect, the equilibrium is not necessarily unique because of the nongeneric character of the game. Specifically, it is trivial to show that it is also subgame perfect for the manufacturer to choose the SS format while the customers randomize—independent of the true value of θ—between $\bar{\theta}$ and $\underline{\theta}$ in their references should they be asked to provide them (though they are not asked to do so in equilibrium). Because manufacturer profits are always higher in the reference format compared with the simultaneous format when it exists—and because customers are indifferent between the equilibria—the former is Pareto-dominant.

provide references after experiencing the product, it would be confident of its exclusive use for at least this period of time. Thus, as long as exclusive use is associated with higher value, Sony's willingness to pay would be expected to increase.

One aspect of this result that merits discussion is the role of competition between customers. Let κ capture the "competitive effect" of the technology in the sense that κ represents the impact on firm i's profit of firm $-i$'s adoption of an effective technology. To begin, we might assume that this impact is independent of the firm i's adoption decision such that $\kappa \equiv \pi_{00} - \pi_{01} = \pi_{10} - \pi_{11}$. High values of κ imply intense competition between the customers; the adoption of the technology by one's competitor has a significant negative impact on profits. It is interesting to note in this regard that κ has two different—and competing—impacts on the reference equilibrium. To analyze this, we normalize π_{01} to 0 and thus $\kappa = \pi_{00} = \pi_{10} - \pi_{11}$. On one hand, it is straightforward to show that $\partial P^A_{\mathrm{RF}}/\partial\kappa > 0$. This can be seen by rewriting the expression for P^A_{RF} using the normalizations and applying the implicit function theorem with respect to κ. This yields the following expression:

$$\partial P^A_{\mathrm{RF}}/\partial\kappa = \frac{pu'(\pi_{11}+\kappa-P^A_{\mathrm{RF}})+(1-p)u'(\kappa-P^A_{\mathrm{RF}})-(1-p)u'(\kappa)}{pu'(\pi_{11}+\kappa-P^A_{\mathrm{RF}})+(1-p)u'(\kappa-P^A_{\mathrm{RF}})},$$

which is positive by virtue of the weak concavity of u. Given that the firm's profits in the RF equilibrium are $P^A_{\mathrm{RF}} + pP^B_{\mathrm{RF}}$, and since $\partial P^B_{\mathrm{RF}}/\partial\kappa = 0$, it is thus clear that the higher the κ is, the higher the firm's profits are in any RF equilibrium. This is intuitive and is essentially the impetus for granting exclusive use of the technology to one customer. On the other hand, however, it is also the case that $\partial P^{B'}_{\mathrm{RF}}/\partial\kappa > 0$; the manufacturer's incentive to deviate from the reference format increases in the competitive intensity between the customers. Thus, whereas increasing competitive intensity makes referencing more and more attractive, it also makes referencing more difficult to sustain in equilibrium. One interpretation of this ambiguous role of competition may be that a moderate level of competition among the firm's customers is most favorable to referencing; when competition is too intense, referencing is not an equilibrium, and when it is not at all intense, we may see referencing but it will be less profitable to the firm.[19]

We may also relax the assumption that there exists a single κ regardless of the firm's own adoption of the technology. That is, the two competitive effects—$\pi_{10} - \pi_{11}$ and $\pi_{00} - \pi_{01}$—could have different magnitudes; the adoption of a new technology by a competitor may be more or less damaging depending on whether one has or has not adopted the technology as well. Contexts in which we might see $\kappa_1 \equiv \pi_{10} - \pi_{11} > \pi_{00} - \pi_{01} \equiv \kappa_0$, for example, could include technologies that aid firms in expanding into new markets. The adoption of such a technology by one's rival is unlikely to cause significant harm unless one is also in that market, perhaps because of the earlier adoption of the same technology. It would be in these markets that our results would suggest that references are particularly attractive because the profitability of the program is driven by a large κ_1 while the enforceability is driven by a small κ_0. On the other hand, it might be the case that $\kappa_1 < \kappa_0$ when the technology enables its buyers to have a disproportionately positive impact on its own customers. Applying the taxonomy in Iyer and Soberman (2000), we might refer to these as "retention technologies." In this case, once one has adopted the technology, the competitor's adoption might have far less of an effect. Here, we would expect to see less use of references because such a program would be both less profitable and more difficult to sustain in equilibrium.

3.3. Model Extensions

In the model we present in §3.2, we make a number of fairly strong assumptions that allow us to isolate cleanly the impact of reference programs. To test the implications of these assumptions, we investigate a number of extensions and discuss here the main findings. The interested reader is directed to the electronic companion for a more detailed and thorough analysis. In §1.1 of the electronic companion, we relax the assumption that the firm can negotiate prices at the customer level, which may limit its ability to "pick and choose" which customers to sell to and when. We show that it may then be possible to implement exclusive use without a reference program. We see this as establishing a boundary condition for our theory and reinforcing the idea that the theory applies specifically to B2B markets, where customer-level price negotiation is the norm.

In §2.1, we address the robustness of our results to our assumption on the timing of profits. Recall that we assume in the core model that the firm does not observe its profits until the end of the game. Our rationale for this was to preclude from our model a situation where a customer learns about the efficacy of his *competitor's* technology via inspection of his *own* profits. In the extension we instead allow for the firm to receive an imperfect signal of the technology's efficacy (perhaps from inspecting its own profits) between the first and second periods. The

[19] It is important to note in this regard that when we speak of "less profitable" referencing at low values of $\pi_{10} - \pi_{11}$, we are not suggesting that it is unprofitable. This is never true when the RF equilibrium (which does not rely on π_{10}) exists.

idea captured here is that the firm's profits are, in reality, an aggregation of hundreds or thousands of entities and programs, the precise understanding of each being difficult to achieve except for a thorough and time-consuming analysis. Our main result in the extension is that, if we allow the manufacturer to price contingent on the realization of the noisy signal (as we do with the reference outcome), the condition for the reference equilibrium is unchanged.

Next, we address an extension in which we allow the manufacturer to condition its decision to facilitate the reference on the efficacy of the technology. Specifically, we allow the firm to only foster the reference when it learns that $\theta = \bar{\theta}$. This model then becomes a game of incomplete information because the manufacturer knows in period 2 the value of θ. As we demonstrate—and which may be somewhat intuitive—the results do not change. There exist only two equilibria in this model: (i) a separating equilibrium in which the manufacturer references only when the technology works and (ii) a pooling equilibrium in which it always references. The key is that the profits are exactly the same in both cases. In (i) the customer rationally infers from the manufacturer's decision the value of θ. Because the information is exactly the same, so are the profits. The existence of a separating equilibrium in this extension suggests that there may be situations in which the firm can use the creation of a reference program to signal more broadly private information it may have about the efficacy of its technology. We investigate this topic in a broader context in §4.

We also analyze an alternative profit formulation in which we relax the assumption in the core model that the firm earns the same profit for an ineffective technology as it does when it does not purchase the technology. In fact, we allow for a different profit for every combination of firm choices and efficacy. Of course, because we add more parameters, it is not surprising that we are again able to demonstrate the existence of a reference equilibrium. More interesting, however, is the fact that this result also shows that the equilibrium does not depend on costless referencing, which is assumed in the main model.

An important simplifying assumption we make in our basic model is that the manufacturer is a monopolist. Of course, in reality, firms in most technology industries are likely to face significant competition, especially for their mature, known technologies. In the electronic companion, we specify a two-firm model in which a second manufacturer has an equivalent "basic" technology—but no equivalent innovation—to that of the focal manufacturer. We show that this has no qualitative effect on our results. In retrospect, this is probably not surprising. We decompose the return associated with product into the core (mature) return π, which is common to both products, and the innovative return $\pi_{w(i),\,w(-i)}$. Because, in equilibrium, the noninnovative firm will be forced to charge a price of zero for the mature product, the same results go through, as demonstrated earlier in this competitive model.

In our model, we have made the standard economic assumption that "talk is cheap" in that agents' actions are profit maximizing conditional on the actions of others. In this regard, we have shown that exclusive use is not implementable by the manufacturer without a reference program. We investigate an extension that instead assumes that the manufacturer's claim that customer A will be the exclusive user of the technology will be upheld in "most cases." We motivate this possible deviation as the random occurrence of a management change or perhaps a change in the environment or a misunderstanding at the outset. It is meant to capture the realistic idea that customers may believe the word of sellers, particularly those with whom they have done business over a long period of time. However, this belief is not absolute; there is an acknowledged small chance that things will change. We show in such a setting that, although the firm may be able to implement exclusive use without it, the reference program is nonetheless useful in that it increases the price at which the product is sold to the early adopter. Intuitively, the reference program helps to eliminate the residual risk that the promise will not be upheld.

Finally, an important institutional detail associated with early adoption and innovative technologies is that early adopters, in addition to serving as references for later adopters, often assist the firm in improving the product itself. We capture this in an extension to the core model by allowing for customer A to provide feedback that increases the probability that the product will work. What we are able to show, first and foremost, is that the reference equilibrium persists under very similar conditions. More interesting, however, is the fact that in such a setting the necessity of risk aversion no longer persists. That is, when the reference account also provides feedback to the firm, referencing may be an equilibrium even when all players are risk neutral. In light of our earlier discussion about the role of risk aversion, this may appear somewhat counterintuitive. However, one must simply notice that the role of risk reduction—the resolution of which provided the incentive for the manufacturer to wait until the second period to sell to the second customer—is partially replicated by the beta program. This is because the information provided by the first customer gives the manufacturer a better product, leading to higher profits in period 2 that it could not capture if it were to deviate and sell to both firms simultaneously.

4. Asymmetric Information

In this section, we analyze a context in which the manufacturer is endowed with private information about the efficacy of its underlying technology. This might be due to, for example, market research undertaken by the firm prior to, or following, its development of the innovation. Analogous to the symmetric information case mentioned previously, the game begins with nature choosing the firm's type. Here, $\theta \in \{\underline{\theta}, \bar{\theta}\}$ is then observed by the manufacturer but not by the potential customers. We assume at the outset that this observation is such that the manufacturer knows θ perfectly. This will be relaxed below. The customers believe the manufacturer to be type $\bar{\theta}$ with probability ϕ. As mentioned previously, firm $\bar{\theta}$'s technology "works" while that of the low-quality firm $\underline{\theta}$ does not. The question we address here is whether the public announcement of a reference program can serve as a signal of quality. In particular, if this is the case, might it allow the firm to capture more value from customer A, the reference account? In general, is announcing publicly that early customers will tell later customers about their experience with the product a credible signal of its quality? One might expect that this would be the case as the game seems to possess a classic single-crossing property. The adoption of a reference program disproportionately benefits firm $\bar{\theta}$ because customer B will never purchase the product from $\underline{\theta}$ in the second period but will be willing to pay $\pi_{11} - \pi_{01}$ to firm $\bar{\theta}$. Note that if the answer is yes—if such a signaling equilibrium indeed exists—this would represent another (and quite distinct) benefit of the firm's management of word of mouth beyond the commitment benefit discussed in §3. One similarity that such a benefit would share with these earlier results is the idea that it would be another example of the reference program providing information to the early adopters and creating value that the firm may capture from these customers.

Our setup in this game mirrors that in the symmetric information game described earlier. Here, each type announces a selling format—either simultaneous sale (SS) or reference (RF). The firm then announces prices for both customers. In the SS format these prices are the same (because the customers are homogeneous), and in the reference format they need not be the same. We denote the high- and low-type's strategies by under- and overscore, respectively. Finally, because our solution concept is perfect Bayesian equilibrium, we need to define off-path beliefs. We capture these beliefs by the term $\mu(F, P) \equiv \Pr[\bar{\theta} \mid F, P]$, which is the probability that the manufacturer is the high type conditional on off-path actions F and/or P.

The following proposition suggests that, in this game, the public announcement of a reference program—which guarantees that the firm's early adopters will (truthfully) tell later adopters about their experiences—can only serve as a signal of quality when the manufacturer is willing to give the product away to these reference accounts for free.

Proposition 5. *There exists a separating equilibrium with* $\bar{F} = \text{RF}$ *and* $\underline{F} = \text{SS}$. *Moreover, it is always the case in such an equilibrium that* $\bar{P}^A_{\text{RF}} = 0$.

Given that the firm types choose different formats in this equilibrium, it implies that customer A knows with certainty that if she is offered a reference contract then the technology works. Therefore, she is willing to pay more than she would have had she been uncertain about its efficacy. Thus, it may be surprising that the high-quality manufacturer is not able to appropriate any of this incremental value. In fact, the firm earns zero profits from the early adopter. The explanation for this lies in the fact that firm $\underline{\theta}$ earns strictly zero profits both on-path and off-path in the second period of any separating equilibrium. This is true on-path because the firm's decision not to reference signals perfectly to both customers that the technology does not work. It is also true off-path because any deviation to a reference format would reveal to customer B that the technology does not work. *Low-quality firms cannot earn profits from late adopters*. Indeed, one might argue that it is the comfort associated with this fact that leads those more risk-averse customers to be late adopters. The low type never earns profits in the second period; it also earns no profits on-path in the first period of a separating equilibrium, because it is revealed to be low quality. Given this, the existence of a separating equilibrium necessarily depends on whether the high type can reduce the low type's ability to earn profits in the first period by deviating to a reference format. As long as $\underline{\theta}$ can earn ϵ profits in the first period, then the separating equilibrium will not exist. Clearly, this would be the case in any separating equilibrium in which $P^A_{\text{RF}} > 0$, since $\underline{\theta}$ would simply offer a reference program, collect P^A_{RF} from customer A, and live with the negative word of mouth, which makes it look no worse to the late adopters than does the announcement that it does not support referencing. To separate from the ineffective technology, the high-type firm needs to impose a cost associated with the reference program, which discourages the low-type firm from mimicking and earning profits in period 1. This leads to $\bar{P}^A_{\text{RF}} = 0$.

An important aspect of this equilibrium is that the off-path beliefs required to support it are not trivial. Specifically, for existence, the separating equilibrium requires that $\mu(RF, P^{A'}_{\text{RF}} > 0) = 0$; customer A must place zero probability on the deviating firm being $\bar{\theta}$.

Whereas this is entirely consistent with the definition of a perfect Bayesian equilibrium (Fudenberg and Tirole 1991), because it is off-path, one can certainly argue that it is unreasonably strong. However, any positive probability that the firm is the high type will yield a strictly profitable deviation for both firms in the first period.

Given the rather severe cost the high-quality firm may need to impose (on both the other type and itself) in order to separate, the question one must ask is whether or not it is worth it. If given the choice, is firm $\bar{\theta}$ willing to bear this cost or might it prefer to accept the customers' uncertainty in the first period? This is addressed in the following proposition.

Proposition 6. *There always exists a pooling equilibrium in which* $\bar{F} = \underline{F} = RF$. *Moreover, this pooling equilibrium strictly dominates the separating equilibrium in that both manufacturer types earn strictly higher profits in this pooling equilibrium than in the separating equilibrium.*

Although it is not surprising that the low type prefers to pool, it may be somewhat less intuitive that this is always true of the high type as well. This result derives from the fact that, in order to separate, the high type needs to give away the technology to the reference customer in the first period. Because the high-type firm earns the same profits in the second period in the pooling and the separating equilibria, its ability to earn positive profits of any magnitude in the first period makes the pooling equilibrium more attractive. Of course, the low-type firm earns zero profits in the second period. However, the pooling outcome allows the firm to earn nonzero profits in period 1 since the customers maintain their prior belief that the firm is the high type with probability ϕ and are thus willing to pay a positive price. In this case, because of pooling, the reference program would seem to offer information only for late adopters, not for early adopters.

For completeness, we also note that there also exists a pooling equilibrium on the simultaneous sale (i.e., no referencing) format. However, this equilibrium may rely on "unreasonable" off-path beliefs as noted in the following proposition.[20]

Proposition 7. *There exists a* ϕ' *such that for all* $\phi > \phi'$ *there is a pooling equilibrium in which* $\bar{F} = \underline{F} = \mathrm{SS}$. *However, there also exists a* $\phi'' > \phi'$ *such that for all* $\phi < \phi''$ *this equilibrium does not satisfy the Intuitive Criterion.*

To support this pooling equilibrium, we need to place a relatively high probability on deviations being implemented by $\underline{\theta}$. Otherwise, such deviations would be profitable. This is true even for all deviations including those in which the deviating firm adopts a reference format that, in addition to fostering the transmission of information, also has the effect of placing more weight on the second-period outcome. Because these are always profitable for the high type but not the low type, the Intuitive Criterion precludes us from placing positive probability on the low type when observing such deviations. Restricting the off-path beliefs in this way—that is, eliminating the possibility that the deviating firm is the low type—results in the elimination of this pooling equilibrium when ϕ is low enough.

Taken together, these results suggest that reference programs may be important selling formats for fostering the spread of information from early lead users to later prospects. However, in equilibrium, they may be of equal use to both high- and low-quality firms because the latter may be unwilling to withstand the negative impact on its quality image associated with *not* having such a program. As a result, references may—perhaps contrary to one's ex ante belief—not be useful as quality signals, even in conjunction with prices as is the case here.

It is important to contrast this result and the associated intuition with the well-known "burning money" theory (Nelson 1974, Milgrom and Roberts 1986).[21] According to this theory, a firm spends money on advertising not necessarily to simply convey information through the content but also to signal with the amount of ads that they are able to spend the money. The result rests on the assumption that better firms have longer-term relationships with their customers and are thus able to recoup the money spent on advertising over a longer and more profitable horizon than can firms with lesser quality products. Thus, their returns on advertising investments are higher, which enables them to spend more. There are several reasons for the deviation between our results here and those found in the burning money literature. On one hand, from a technical perspective, Milgrom and Roberts (1986) do not fully consider the relative attractiveness of the pooling and separating equilibria. They argue that the informational requirements associated with the former may be difficult to meet. A second and more fundamental difference is the nature of the firm's information. Specifically, we assume that the technology either works or does not work and that the manufacturer is endowed with this information perfectly. In the next section, we relax this assumption and demonstrate that referencing, in fact, may be an informative signal in some contexts.

[20] It is obvious that there is no separating equilibrium in which $\bar{\theta}$ sells simultaneously and $\underline{\theta}$ references. There will always be a profitable deviation because the latter will always deviate to SS.

[21] The generality of the relationship between quality and advertising has been questioned by Horstmann and Moorthy (2003).

4.1. Noisy Private Information

Whereas most of the traditional signaling models in the literature have modeled the firm's private information as being perfect (Wernerfelt 1990, Moorthy and Srinivasan 1995, Simester 1995, Desai 2000, Anand and Shachar 2007), we provide an alternative specification in this section in which the signal is a noisy one. As motivation, recall that the separating equilibrium in which a firm provides references to later adopters if and only if its technology works is not an attractive one because the firm with the effective technology needs to impose (and withstand) an extremely high cost to enforce separation. Because, as described above, the low-quality firm is mainly concerned with sales in the short term, one potential variant of the game might be to focus on alternative specifications in which the low-type firm's profit in the first period is somehow improved. In this section, we consider a context in which, rather than receiving a perfect signal of nature's choice, the manufacturer receives an imperfect one. Specifically, we assume here that firms receive a signal that they are $\bar{\theta}$ with either probability $\bar{\gamma}$ or probability $\underline{\gamma}$, where $1 > \bar{\gamma} > \underline{\gamma} > 0$. The assumption that $\bar{\gamma} > \underline{\gamma}$ captures the idea that some firms are "probably" better than others. Note, of course, that we have solved above the boundary cases. Everything else about the game remains the same as above. In particular, though the manufacturer receives an imperfect signal initially, both it and customer A are able to assess θ perfectly following the technology's implementation in the first period.

In this setup, the key condition for the existence of a separating equilibrium in which the firm provides references if and only if its technology is likely to work is

$$P^A_{\mathrm{RF}}(\bar{\gamma}) + \bar{\gamma}P^B_{\mathrm{RF}} \geq 2P_{\mathrm{SS}}(\underline{\gamma}) \geq P^A_{\mathrm{RF}}(\bar{\gamma}) + \underline{\gamma}P^B_{\mathrm{RF}},$$

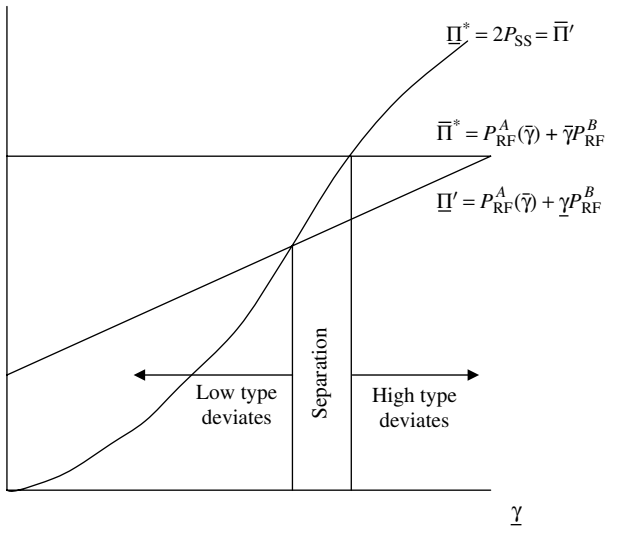
where the left-hand inequality ensures that the high-type firm does not deviate and the right-hand inequality ensures that the low type does not deviate. Because the reference will provide customer B with perfect information about θ, P^B_{RF} (unlike P^A_{RF}) is not a function of γ. In addition to this, we must again define off-path beliefs $\mu(F, P)$. The question is whether this model, unlike that above, yields a cheap separating equilibrium in which the high-quality firm does not need to distort prices to customer A in order to enforce separation. Intuitively, we would expect that this might be the case because the low-quality firm in this model is able to earn on-path profits by selling to both customers in the first period, albeit at lower prices than those offered by $\bar{\theta}$. However, any deviation to a reference format would lead to higher prices from the early adopters but lower prices from the later adopters (because the reference will reveal that $\theta = \underline{\theta}$). The relative magnitudes of these quantities will determine the existence of the equilibrium. As the following proposition demonstrates, this will depend critically on the magnitude of $\underline{\gamma}$.

Proposition 8. *Let $\bar{\gamma} \to 1$; then when π_{10} is not too large, there exists a nonempty set Γ such that for all $\underline{\gamma} \in \Gamma$ there exists a cheap separating equilibrium in which $\bar{\theta}$ adopts a reference format and charges prices $P^A_{\mathrm{RF}}(\bar{\gamma})$ and P^B_{RF}, and $\underline{\theta}$ sells to both customers simultaneously at price $P_{\mathrm{SS}}(\underline{\gamma})$. Moreover, it is always the case that there exists a $\hat{\gamma} > 0$ such that $(0, \hat{\gamma}) \notin \Gamma$.*

Thus, by modifying the model to allow the low-quality firm to receive less accurate (though, on average, more optimistic) information, we are now able to establish the existence of an equilibrium in which firms that, in expectation, are of higher quality will seek out references while lower-quality firms will not. Because the equilibrium is cheap—involving no distortion of prices by $\bar{\theta}$—it cannot be unambiguously dominated by a pooling equilibrium. The high-quality firm can do no better than full separation in this cheap equilibrium.

See Figure 3 for a graphical illustration of this result as well as the intuition behind its proof. Note that although we present $\underline{\Pi}^*$ as being S-shaped, the actual shape is highly dependent on the shape of $u(z)$. As a result, Γ may consist of nonconnected regions. Several other important features of this model are clear in this figure. First, as stated in Proposition 8, the separating equilibrium requires intermediate values of $\underline{\gamma}$. At very high values of $\underline{\gamma}$, the high-quality firm deviates from the separating equilibrium and sells to both firms in the first period. As in Proposition 1, the expected gain from waiting for the word-of-mouth recommendations to improve customer B's willingness to pay

Figure 3 Separating Equilibrium in the Asymmetric Model



is not worth losing the opportunity to capture value from this customer for his use of the technology over two periods. At very low values—indeed, as $\underline{\gamma} \to 0$—we revert back to the result above in Proposition 6. Moreover, it is easy to discern from Figure 3 that distortions by the high-quality firm to lower values of P^A_{RF} will clearly yield separation for lower values of $\underline{\gamma}$. This can be seen by noting that any decrease from P^A_{RF} to $P^A_{\mathrm{RF}} - \varepsilon$ shifts the $\bar{\Pi}^*$ and $\underline{\Pi}'$ curves down by ε. Since $\underline{\Pi}^*$ is strictly increasing, it is clear that the $\gamma \in \Gamma$ decline as well. Note that the same occurs if there were a cost ψ associated with the reference program. Finally, Figure 3 suggests what happens when $\bar{\gamma}$ takes on lower values. Since, by assumption, $\underline{\gamma} < \bar{\gamma}$, the choice of the latter can be visualized in Figure 3 by drawing a vertical line at some point extending from the x axis. Everything to the left of this line is an acceptable set of parameters. Everything to the right is not. Thus, one can determine simply that for $\bar{\gamma}$ low enough, the separating equilibrium does not exist.

4.2. Discussion: Consumer Word of Mouth

We conclude by noting that one can compare our results in this section to the more commonly studied domain of word of mouth in consumer markets. Notably, Mayzlin (2006) finds that online WOM by consumers is credible even though, in her model, it is disproportionately manipulated by inferior firms. The two fundamental distinctions between the models analyzed in Mayzlin (2006) and studied here are the fact that the customers in this model are assumed to compete with each other and that the firm is able to make take-it-or-leave-it price offers to each customer individually. However, neither would seem to preclude the application of the core idea to a consumer setting. We might imagine that in some markets—fashion, for example—even consumers would consider themselves to be in "competition" with each other in the sense that being "first" has disproportionate social value. This might be seen as being analogous to the monopoly profits we specify in the business-to-business model. Moreover, although individual customer pricing is not common in consumer markets, the adjustment of prices across time certainly is. Because, in our model, prices are never different across customers within a time period, one could certainly make the argument that our model captures a firm's dynamic pricing strategy in an effort to target different segments such as early and late adopters.

Given this, it is interesting to compare our result in Proposition 8 to Mayzlin's (2006) key result. Using her defining example of a music recording artist, our model would apply to a context in which there is utility to consumers to being first to identify a new talent. As long as the record company received an imperfect signal of quality and as long as the lower-quality artist was not of "too low" quality, then our results would suggest that a mechanism such as a "refer-a-friend" program in which early fans were encouraged to tell others about artist would not only foster the flow of information about artists to new customers but also increase in the minds of these initial fans the belief that the artist is of high quality. That is, the invitation to share one's honest thoughts about the product could serve as a signal of quality. In this way, we view our results as complementary to those of Mayzlin (2006) in that they suggest that WOM is useful not only in increasing the willingness to pay of the *recipients* of valuable peer-to-peer information but also in accomplishing the same result for the *senders* of this information.

5. Conclusions, Limitations, and Opportunities for Future Research

We have demonstrated that the firm may benefit in several ways from fostering the flow of information from early adopters of its products to potential later adopters. These potential benefits come in two forms. On one hand, we have shown that the commitment to a reference program makes credible a claim of exclusive use. In this way, the program facilitates the creation of more customer value that the firm may appropriate. We also show that when the firm has private information about the efficacy of its technology, a reference program can serve as a signal to early adopters of high efficacy. Both of these have the effect of increasing the willingness to pay of early adopters. It is important to emphasize that we do not see our results as suggesting that these strategic implications of referencing represent the predominant motivation for the widespread use of reference programs. Indeed, it is likely that the primary objective for most firms in implementing these programs is to increase the willingness to pay of risk-averse late adopters. Nonetheless, we see our results as demonstrating important, and heretofore unappreciated, implications of reference programs that merit the attention of both scholars and managers.

We have attempted to include the important characteristics of the B2B setting we have modeled, but there are, of course, a number of important limitations, each of which may provide interesting opportunities for future research. First, we have assumed that the customers of the firm are identical. In reality, of course, there are many dimensions along which these firms are likely to differ. We discuss in Footnote 17 a simple case, but there remains a range of interesting questions one could study once one allows for heterogeneity among customers. In particular, we would expect that some of these dimensions would make some customers better reference accounts than

others. It would be interesting to study what these dimensions might be and how they might relate to the manufacturer's optimal sequencing of customers. That is, which customers—were the firm to have the choice—should be the early, reference customers?

A strong assumption we make in our analysis is that word of mouth from customer A to customer B is a perfect signal of the latter's outcome. Of course, this is unlikely to be the case. The fact that another firm had a positive experience might be a good signal, but it is likely that some residual uncertainty may remain. This residual may be due to either (a) imperfect communication or (b) differences in the level or type of value the technology would provide to each of the firms. It would be interesting to study what impact this assumption would have and what it might say about who should serve as a reference account.

Our focus here is on the strategic impact of customer references. Of course, there are many other reasons why individuals might be willing to provide references for other firms, or even for competitors. Serving as a reference for a brand name firm can increase the individual's visibility, for example. It might also help the individual to expand her social network. Given the high turnover rate for chief technology officers, for example, the opportunity to meet others in the same industry may be valuable in the long run. it would be very interesting to investigate the extent to which (and manner in which) firm-level profit maximization factors interact with these individual-level objectives in terms of decisions about whether and when to serve as a reference.

As noted in §2, references are often used in the firm's traditional marketing. Although many potential customers may see these communications, one could argue that, conceptually, the impact of such an approach—transmitting information from customer A to many customer Bs—is similar to what we model above. On the other hand, there are a number of interesting aspects of this activity that might warrant future study. For example, the prospect of "cherry-picking" by the manufacturer is greatly enhanced in such a setting. The impact of this is not entirely clear. Moreover, appearing publicly on behalf of a particular product may act as a signal of some unobservable quality for the reference. A question arises as to which firm benefits from such an inference and thus where the surplus will be generated and extracted. Given this, what are the expected patterns of such announced "partnerships": are they likely to exist between highly asymmetric or very similar firms? Finally, such a public announcement is likely to result in de facto exclusivity: the chief information officer at Delta Airlines is unlikely to publicly endorse two firms in a given space. This may in some cases lead to competition at the manufacturer level for attractive references. How this plays out and how it impacts the split of surplus created may yield interesting insights.

Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://mktsci.journal.informs.org/.

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Appendix. Proofs

Proof of Proposition 1. The manufacturer does not deviate iff the following inequality holds:

$$P_{\mathrm{RF}}^{B'} < pP_{\mathrm{RF}}^{B}, \tag{10}$$

since the left-hand side represents the manufacturer's revenue from customer B when it deviates to offering the product in period 1, and the right-hand side is the revenue it gets contingent on a positive reference in period 2. Now, we assess the necessary conditions.

Condition (i) π_{11} is high relative to π_{00}: Assume that $\pi_{11} = \pi_{00}$. Substitution of this restriction into (9) yields

$$u(\pi_{00} - P_{\mathrm{RF}}^{B'}) + u(\pi_{00}) = 2[pu(\pi_{01}) + (1-p)u(\pi_{00})].$$

Assume as well that (10) holds. This implies that

$$u(p\pi_{01} + (1-p)\pi_{00}) + u(\pi_{00}) < 2[pu(\pi_{01}) + (1-p)u(\pi_{00})],$$

which is a contradiction since $u(p\pi_{01} + (1-p)\pi_{00}) > pu(\pi_{01}) + (1-p)u(\pi_{00})$ by Jensen's inequality, and $u(\pi_{00}) \geq pu(\pi_{01}) + (1-p)u(\pi_{00})$ since $\pi_{01} \leq \pi_{00}$.

Condition (ii) the customer is sufficiently risk averse: Assume that $u(x) = x$. Then, (9) becomes

$$\begin{aligned} p(\pi_{11} - P_{\mathrm{RF}}^{B'}) + (1-p)(\pi_{00} - P_{\mathrm{RF}}^{B'}) + [p\pi_{11} + (1-p)\pi_{00}] \\ = 2(p\pi_{01} + (1-p)\pi_{00}), \end{aligned}$$

which can be simplified to yield

$$P_{\mathrm{RF}}^{B'} = 2p(\pi_{11} - \pi_{01}),$$

which contradicts (10).

Condition (iii) p is not too high: Assume $p \to 1$; then (9) approaches

$$u(\pi_{11} - P_{\mathrm{RF}}^{B'}) + u(\pi_{11}) = 2u(\pi_{01}).$$

Assuming (10) holds implies that $u(\pi_{01}) + u(\pi_{11}) < 2u(\pi_{01})$, which is a contradiction. □

Lemma 1. *Define constants u_a, u_b, a, b, and d such that $0 < u_a < u_b$ and $0 < a < b$ and $d > 0$. Then, for some $c \in (a, b)$, we can find a continuous, twice-differentiable, positive-valued function $v(x)$ such that $v' > 0$, $v'' \le 0$, $v(a) = u_a$, $v(b) = u_b$, $v(c) \le u_b$, and $v'(c) = d$ if and only if*

$$d < \frac{u_b - u_a}{c - a}.$$

Proof of Lemma 1. Let $v(a) = u_a$ and $v(b) = u_b$. Now, we want to draw a concave curve that passes through these points while also having $v'(c) = d$. Assume that $v'(c) = d > (u_b - u_a)/(c - a)$. By the Fundamental Theorem of Calculus, this implies that

$$\begin{aligned} v(c) - v(a) &= \int_a^c v'(s)\,ds \\ &\ge d(c - a) \\ &> u_b - u_a, \end{aligned}$$

where the first inequality follows from the fact that v is concave. The second inequality is our premise. However, since $v(a) = u_a$, this implies that $v(c) > u_b$, which is a contradiction. To prove sufficiency, assume that we cannot draw a line of slope d' at c satisfying the above conditions. On one hand, it is clear from the mean value theorem that any slope of less than $(u_b - u_a)/(b - a)$ is possible. Thus, we know $(u_b - u_a)/(b - a) < d'$. Given concavity, the maximum slope at any given point on v is given by the slope of a straight line from $v(a)$ to the maximum value of $v(c)$, given the constraints. Thus, d' is greater than the slope of this line or $d' > (u_b - u_a)/(c - a)$, which yields the contradiction. □

Proof of Proposition 2. As $p \to 0$, both $P_{\mathrm{RF}}^{B'}$ and pP_{RF}^{B} vanish. Thus, the objective is to compare the relative slopes as $p \to 0$. Differentiating $P_{\mathrm{RF}}^{B'}$ with respect to p and letting the latter approach zero yields

$$\begin{aligned} \frac{\partial P_{\mathrm{RF}}^{B'}}{\partial p} &= \frac{u(\pi_{11} - P_{\mathrm{RF}}^{B'}) - u(\pi_{00} - P_{\mathrm{RF}}^{B'}) + u(\pi_{11}) - u(\pi_{00})}{pu'(\pi_{11} - P_{\mathrm{RF}}^{B'}) + (1-p)u'(\pi_{00} - P_{\mathrm{RF}}^{B'})} \\ &\overset{p\to 0}{\to} \frac{2[u(\pi_{11}) - u(\pi_{01})]}{u'(\pi_{00})}. \end{aligned}$$

Assume that (10) does not hold such that

$$\frac{2[u(\pi_{11}) - u(\pi_{01})]}{u'(\pi_{00})} > \pi_{11} - \pi_{01} \iff \frac{2[u(\pi_{11}) - u(\pi_{01})]}{\pi_{11} - \pi_{01}} > u'(\pi_{00}).$$

Let $d = (2[u(\pi_{11}) - u(\pi_{01})])/(\pi_{11} - \pi_{01})$. By Lemma 1, we can can choose a proper utility function with $u(\pi_{01})$ and $u(\pi_{11})$ and $u'(\pi_{00})$ as long as

$$\frac{2[u(\pi_{11}) - u(\pi_{01})]}{\pi_{11} - \pi_{01}} \le \frac{u(\pi_{11}) - u(\pi_{01})}{\pi_{00} - \pi_{01}} \iff \pi_{00} \le \frac{\pi_{11} + \pi_{01}}{2},$$

which yields our contradiction. □

Proof of Proposition 3. Since pP_{RF}^{B} is linear in p and vanishes as $p \to 0$, and since $P_{\mathrm{RF}}^{B'} > pP_{\mathrm{RF}}^{B}$ as $p \to 1$ (Proposition 1), it is sufficient to show that $P_{\mathrm{RF}}^{B'}$, which also vanishes as $p \to 0$, is strictly convex and that $\partial P_{\mathrm{RF}}^{B'}/\partial p|_{p=0} < \partial pP_{\mathrm{RF}}^{B}/\partial p|_{p=0} = \pi_{11} - \pi_{00}$. For convexity, let $\pi_{01} \to \pi_{00}$ and twice apply the implicit function theorem to (9) to yield

$$\begin{aligned} \frac{\partial^2 P_{\mathrm{RF}}^{B'}}{\partial p^2} = \Bigg(\frac{\partial P_{\mathrm{RF}}^{B'}}{\partial p} \Bigg[&-2u'(\pi_{11} - P_{\mathrm{RF}}^{B'}) + 2u'(\pi_{00} - P_{\mathrm{RF}}^{B'}) \\ &+ \frac{\partial P_{\mathrm{RF}}^{B'}}{\partial p}(pu''(\pi_{11} - P_{\mathrm{RF}}^{B'}) + (1-p)u''(\pi_{00} - P_{\mathrm{RF}}^{B'})) \Bigg] \Bigg) \\ &\cdot (pu'(\pi_{11} - P_{\mathrm{RF}}^{B'}) + (1-p)u'(\pi_{00} - P_{\mathrm{RF}}^{B'}))^{-1}. \end{aligned}$$

Since both $\partial P_{\mathrm{RF}}^{B'}/\partial p$ and the denominator are strictly positive, we focus on establishing the sign of the bracketed expression. We now impose the assumption that $u(z) \equiv -\exp(-rz)$. To aid in the exposition, we make the following definitions: $E_{11} \equiv \exp(-r\pi_{11})$, $E_{00} \equiv \exp(-r\pi_{00})$ and $E_P \equiv \exp(rP_{\mathrm{RF}}^{B'})$. This gives us

$$\begin{aligned} \operatorname{sgn}\left[\frac{\partial^2 P_{\mathrm{RF}}^{B'}}{\partial p^2}\right] = \operatorname{sgn}\Bigg[&-2rE_P(E_{11} - E_{00}) \\ &- \frac{\partial P_{\mathrm{RF}}^{B'}}{\partial p} r^2 E_P(pE_{11} + (1-p)E_{00}) \Bigg], \end{aligned} \tag{11}$$

where

$$\begin{aligned} \frac{\partial P_{\mathrm{RF}}^{B'}}{\partial p} &= \frac{u(\pi_{11} - P_{\mathrm{RF}}^{B'}) - u(\pi_{00} - P_{\mathrm{RF}}^{B'}) + u(\pi_{11}) - u(\pi_{00})}{pu'(\pi_{11} - P_{\mathrm{RF}}^{B'}) + (1-p)u'(\pi_{00} - P_{\mathrm{RF}}^{B'})} \\ &= \frac{(E_{00} - E_{11})(E_P - 1)}{rE_P(pE_{11} + (1-p)E_{00})} \ge 0, \end{aligned} \tag{12}$$

which we can now substitute into (11) to yield

$$\begin{aligned} \operatorname{sgn}\left[\frac{\partial^2 P_{\mathrm{RF}}^{B'}}{\partial p^2}\right] &= -r \cdot \operatorname{sgn}[2E_P(E_{11} - E_{00}) + (E_{00} - E_{11})(E_P + 1)] \\ &= -r \cdot \operatorname{sgn}[(E_{00} - E_1)(1 - E_P)] > 0, \end{aligned}$$

which proves convexity. Now, we compare the slopes of pP_{RF}^{B} and $P_{\mathrm{RF}}^{B'}$ as $p \to 0$. From (12), and noting that $P_{\mathrm{RF}}^{B'} \overset{p\to 0}{\to} 0$ and, thus, $E_P \overset{p\to 0}{\to} 1$, we can see that $\partial P_{\mathrm{RF}}^{B'}/\partial p \overset{p\to 0}{\to} 0$. □

Proof of Proposition 4. By construction, $\Pi_{\mathrm{SS}} = 2P_{\mathrm{SS}}$ and $\Pi_{\mathrm{RF}} = P_{\mathrm{RF}}^{A} + pP_{\mathrm{RF}}^{B}$. Assume that the firm can commit credibly but $\Pi_{\mathrm{SS}} > \Pi_{\mathrm{RF}} \Longrightarrow 2P_{\mathrm{SS}} > P_{\mathrm{RF}}^{A} + pP_{\mathrm{RF}}^{B}$. However, given that commitment is credible, we know that $P_{\mathrm{RF}}^{B'} = P_{\mathrm{SS}} < pP_{\mathrm{RF}}^{B}$. Moreover, P_{RF}^{A} is characterized by the following implicit equation:

$$\begin{aligned} &pu(\pi_{10} - P_{\mathrm{RF}}^{A}) + (1-p)u(\pi_{00} - P_{\mathrm{RF}}^{A}) + [pu(\pi_{11}) + (1-p)u(\pi_{00})] \\ &\quad = 2[pu(\pi_{01}) + (1-p)u(\pi_{00})], \end{aligned}$$

which implies that $P_{\mathrm{RF}}^{A} > P_{\mathrm{SS}}$, which yields our contradiction. As noted in the text after the proposition, the following is also subgame perfect: the manufacturer chooses the SS format and customers randomize between $\bar{\theta}$ and $\underline{\theta}$ in their reference to the other customer if they are asked to do so. The firm's unilateral deviation to the reference format would not yield strictly higher profits because of the customers' credible (because of indifference) threat of randomization. As shown above, when the reference equilibrium exists, it Pareto dominates such an equilibrium. □

Proof of Proposition 5. First, let $\bar{P}_{\mathrm{RF}}^{A} = 0$, $\bar{P}_{\mathrm{RF}}^{B} = \pi_{11} - \pi_{01}$, and $\underline{P}_{\mathrm{SS}}$ be the full information optimum. Then, on-path profits are $\bar{\Pi} = \bar{P}_{\mathrm{RF}}^{B}$ and $\underline{\Pi} = 0 = \underline{P}_{\mathrm{SS}}|_{p\to 0}$. Since $\underline{\theta}$ cannot

sell in period 2 with a reference, there is no strictly better deviation on format alone. Deviation to RF and $P > 0$ are prevented only by $\mu(RF, P > 0) = 0$ since anything nonzero would yield a profitable deviation. Assume that such a separating equilibrium exists with $\bar{P}^A_{RF} > 0$, $\bar{P}^B_{RF}$, and $\underline{P}_{SS}$. On-path profits are $\bar{\Pi} = \bar{P}^A_{RF} + p\bar{P}^B_{RF}$ and $\underline{\Pi} = 2\underline{P}_{SS}$. It is obvious that $\underline{P}_{SS} = 0$ since $\theta = \underline{\theta}$. Thus $\underline{\Pi} = 0$. If the low type deviates to $\underline{F}' = RF$ and $\bar{P}^A_{RF}$ and $\bar{P}^B_{RF}$, it earns strictly higher profits, which yields a contradiction. □

Proof of Proposition 6. Efficient first-period prices in such an equilibrium P^A_{RP} would be given by the following implicit equation:

$$\phi u(\pi_{10} - P^A_{RP}) + (1-\phi)u(\pi_{00} - P^A_{RP}) + [\phi u(\pi_{11}) + (1-\phi)u(\pi_{00})] = 2[\phi u(\pi_{01}) + (1-\phi)u(\pi_{00})]. \quad (13)$$

On-path profits are

$$\bar{\Pi} = P^A_{RP} + \pi_{11} - \pi_{01},$$
$$\underline{\Pi} = P^A_{RP}.$$

A deviation to any $P^{A'}_{RP} < P^A_{RP}$ is unprofitable for both, regardless of μ. Prevention of a deviation to $P^{A'}_{RP} > P^A_{RP}$ requires that $\mu(\text{RF}, P^{A'}_{RP}) \le \phi$. A deviation to $F = \text{SS}$ would similarly require that $\mu(\text{SS}, P^{A'}_{RP})$ not be too large relative to ϕ. For example, at $\mu(\text{SS}, P^{A'}_{RP}) = 0$, the pooling equilibrium always holds. To see that this pooling equilibrium Pareto dominates the separating equilibrium, first note that, for $\bar{\theta}$, second-period profits are the same in the two equilibria while $P^{A'}_{RP} > 0$ as long as $\phi > 0$. For $\underline{\theta}$, since $P^{A'}_{RP} > 0$, $\underline{\Pi} > 0$. □

Proof of Proposition 7. Efficient prices in this equilibrium are P_{SP}, given by the following implicit equation:

$$\phi u(\pi_{11} - P_{SP}) + (1-\phi)u(\pi_{00} - P_{SP}) + [\phi u(\pi_{11}) + (1-\phi)u(\pi_{00})] = 2[\phi u(\pi_{01}) + (1-\phi)u(\pi_{00})].$$

Clearly, deviation to any $P'_{SP} < P_{SP}$ would be unprofitable. Deviation by either firm to $P'_{SP} > P_{SP}$ would be precluded by $\mu(\text{SS}, P'_{SP}) \le \phi$. Deviation to $F = RF$ is strictly more profitable for $\bar{\theta}$ than for $\underline{\theta}$, so we focus there. We note the following: (i) $\partial P_{SP}/\partial\phi > 0$, (ii) $P_{SP} \overset{\phi\to 0}{\to} 0$, and (iii) $\bar{\Pi}' \overset{\mu(\text{SS}, P_{SP})\to 0}{\longrightarrow} \pi_{11} - \pi_{01}$. Combined, these demonstrate that when ϕ is low enough, firm $\bar{\theta}$ will have a profitable deviation. On the other hand, when ϕ is higher, we can always choose a μ such that the deviation is prevented and the equilibrium exists. Thus, there exists a ϕ' and $\mu(RF, P')$ such that for all $\phi > \phi'$, there exists a pooling equilibrium on SS. For example, when $\mu(RF, P') = 0$, ϕ' is given by the following implicit equation:

$$2P_{SP}(\phi') = \pi_{11} - \pi_{01}.$$

Of course, for higher values of μ, ϕ' and $P_{SP}(\phi')$ are higher. Now, to check whether the equilibrium satisfies the Intuitive Criterion (Cho and Kreps 1987), we consider the following deviation by $\bar{\theta}$: $P^{A'}_{RF} = P_{SP}$ and $P^{B'}_{RF} = \pi_{11} - \pi_{01}$. In this deviation, the manufacturer does not change the price but adopts the reference format, which ensures that $\underline{\theta}$ does not sell in the second period. Note that $\underline{\theta}$'s on-path profits are $\underline{\Pi} = 2P_{SP}$, which is strictly more than P_{SP}, the highest profit that $\underline{\theta}$ could earn if it were the deviating firm (since customer B will learn that the product does not work). Thus, according to the Intuitive Criterion, we cannot place positive probability on $\underline{\theta}$ in the off-path beliefs. Given this, customer A will surely buy in period 1 at $P^{A'}_{RF} = P_{SP}$ and create the reference that proves to customer B that $\theta = \bar{\theta}$. Moreover, customer B will surely buy in period 2. All that remains to be checked is whether this represents a profitable deviation for $\bar{\theta}$. This would be the case when $P_{SP}(\phi) < \pi_{11} - \pi_{01}$. Thus, for all $\phi < \phi''$—where ϕ'' is defined by $P_{SP}(\phi'') = \pi_{11} - \pi_{01}$—the equilibrium does not satisfy the Intuitive Criterion. It is clear that at low values of μ, $\phi'' > \phi'$. □

Proof of Proposition 8. On-path profits in such a separating equilibrium would be $\bar{\Pi} = \bar{P}^A_{RF} + \bar{\gamma}P^B_{RF}$ and $\underline{\Pi} = 2\underline{P}_{SS}$, where the under- and overscore capture the fact that the prices are a function of $\underline{\gamma}$ and $\bar{\gamma}$, respectively. Note that P^B_{RF} is only paid conditional on a positive reference and is thus not a function of γ. Deviation profits available to $\underline{\theta}$ if it were to deviate to RF are $\underline{\Pi}' = \bar{P}^A_{RF} + \underline{\gamma}P^B_{RF}$. Were $\bar{\theta}$ to deviate to SS, it would earn $\bar{\Pi}' = 2\underline{P}_{SS} = \underline{\Pi}$. Off-path beliefs low enough would guarantee that this is the optimal price for such a deviation. As $\underline{\gamma} \to 0$, it is clear that $\underline{\Pi} = 2\underline{P}_{SS} = 0 < \bar{P}^A_{RF} = \underline{\Pi}'$. Also, as $\underline{\gamma} \to 1$, we know from Proposition 1, condition (iii), that $\underline{P}_{SS} > \underline{\gamma}P^B_{RF}$ and $\underline{P}_{SS} - \bar{P}^A_{RF}$ can be made arbitrarily small with small values of π_{10}. Since $2\underline{P}_{SS}$ is continuous in $\underline{\gamma}$, this proves the claim. □

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