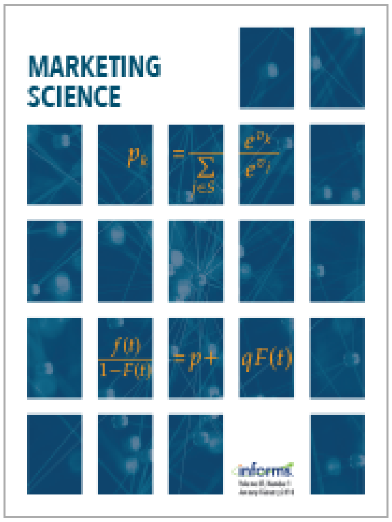

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Intraconnectivity and Interconnectivity: When Value Creation May Reduce Profits

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This paper analyses firms' decisions to provide connectivity to their customers. We distinguish between intraconnectivity—the ability of one firm's customers to connect to each other—and interconnectivity—the ability of one firm's customers to connect with another firm's customers. The profitability implications of allowing connectivity are not a straightforward consequence of the consumer value of connectivity, because connectivity affects not only the customer value but also the intensity of competition by creating or changing network externality. We find that if sales are driven by brand switching rather than by category expansion, a firm may find it optimal not to provide intraconnectivity even if providing it is not costly and may find it optimal to provide interconnectivity even at a cost exceeding the consumer value of connectivity. On the other hand, if category expansion is possible, providing intraconnectivity may be profitable. In this case, either the equilibrium intraconnectivity provision may be asymmetric or both firms may find it (individually) optimal to provide intraconnectivity. Under certain conditions in the latter case, the firms' choice of intraconnectivity is a prisoner's dilemma game.

Key words: network externality; product design; pricing; competitive strategy; game theory
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1. Introduction

Traditionally, we view a product as providing utility or value to its consumers irrespective of any interaction a consumer has with other consumers. However, sometimes the value a consumer derives from using a product could increase if this product can be connected with like products of the other consumers. In such a case, the utility a consumer derives from using the product depends on the number of products sold and on the ability of products to connect to each other. This is a special case of what is known as a market with positive network externality, i.e., a market where a consumer derives higher utility from a product when more consumers have the product. In this paper, we will use the terms "product" and "consumer connectivity" interchangeably. We define connectivity as the ability of consumers to connect to each other through products they use or the ability of consumers to connect their products and enhance the utility they obtain from the product.

To better understand what we mean by connectivity and the different types of connectivity, consider the following example of a video game console, say, PlayStation 2 (PS2), with a particular game playable on it. If the game is a multiplayer game, a PS2 console would provide a higher value to the consumer if the customer could connect it to other PS2 consoles—say, through a telephone line—to play this game with other users. The decision whether to make it possible for PS2 consoles to communicate with each other is the connectivity decision of the PS2 manufacturer, Sony. We will refer to this decision as the decision on intraconnectivity, where the prefix "intra" refers to connectivity between products of the same firm.

If another console, say, GameCube, produced by another company, Nintendo, also has a version of the same game, the two manufacturers could each introduce the functionality of connecting its console to a console of the competing company in order to play the multiplayer game. We will refer to this second type of connectivity as interconnectivity, where the prefix "inter" refers to connectivity between different (e.g., competing) types of products. Because different consoles have a different set of games, the interconnectivity possibilities could be more limited than the intraconnectivity ones in this example.

Note that when we are looking at the decisions of a video game developer, the multiplayer option of the game, even when only playable through the same PC or game console, can be a type of intraconnectivity if players who are interested in playing the game in multiplayer mode would normally each own a copy of the game. The latter may be realistic because a consumer who owns a version of a particular game could be much more skillful at it than a consumer who does not, and therefore, a consumer who has a particular game with a multiplayer option would mostly be interested in playing ("connecting") with other consumers who also purchased the game. Although it is difficult to imagine interconnectivity among different video games in the video game connectivity example, interconnectivity may be an easier option to envision in other product categories, such as cell phone networks (e.g., a customer of Sprint calling a customer of AT&T) or time-share companies. As another example, consider a portable music player, a telephone, and a multifunctional cell phone that combines the functionality of a music player and a telephone. The first may be viewed as providing utility to a consumer irrespective of other consumers, the second may be viewed as providing utility only if there are other consumers who own the telephones, and the third is a product that provides utility to its consumer even if there are no other consumers of the same device, but which provides a higher utility if there are more consumers owning it. Should a firm producing the first product (music player) enhance it with the cell phone functionality? Although such products now exist, one may wonder why they were not introduced earlier or whether their connectivity functionality is artificially limited. Note that whereas the intraconnectivity decision is the decision of the respective company alone, interconnectivity can only be used if both of the companies provided such functionality.

The goal of this paper is to investigate the optimal choices of a firm to provide intra- and interconnectivity to its consumers and to help understand when these options would arise in equilibrium of a competitive market. Our main findings are the following: (i) intraconnectivity, even when it is not costly to the firm, may decrease the firms' profits in a competitive environment, whereas (ii) interconnectivity could increase a firm's profits by an amount even higher than consumer value of interconnectivity.

To understand the reason for the above finding about intraconnectivity, consider the following. The effect of intraconnectivity on a firm's profits is threefold. First, providing connectivity adds value to consumers, and this could potentially lead to higher profits for the firm either through increased market share (sales) or through the ability to charge a higher price without losing market share. Second, once the product has an intraconnectivity feature, the firm realizes that if it were to reduce price, it would gain market share not only because the consumers are attracted by the lower price but also because expecting higher sales, the consumers now expect a higher value of the product. In other words, when the product has an intraconnectivity feature, the firm has an extra incentive to lower its price. Third, the competing firm, expecting to lose market share because of the two effects above, will find it optimal to decrease its price as well. This will have a negative effect on the focal firm's profits. The combination of the three effects above determines the ultimate profitability of intraconnectivity.

Let us compare the above situation to the case of a more standard product improvement where a firm can enhance value of its product by the same amount to all consumers regardless of its market share. In this case, the firm may expect higher sales as a result of providing higher value; it will further find it optimal to increase price, albeit by an amount lower than the extra value provided; and given that the competitor expects the first firm to increase the price by an amount lower than the extra value, the competitor would find it optimal to reduce price. These three effects correspond to the three effects of the intraconnectivity discussion above. However, because of the extra incentive to reduce price to increase value (the effect of positive network externality on price), the final effect of intraconnectivity provision on a firm's own price is not clear, and the effect of intraconnectivity provision on the price of the competing firm is even more severe than in the more usual case of product improvement. Thus although the "standard" product improvement discussed above is beneficial to the firm, product improvement through intraconnectivity provision need not be.[1] We show that when a firm offers intraconnectivity and regardless of the other firm's intraconnectivity choice, the negative strategic effects (increased competition) may dominate the positive value-creation effect and result in lower profits to the firm relative to the case when this firm does not offer intraconnectivity, and in equilibrium, neither firm may offer intraconnectivity. In addition, what we find is that contrary to the case of the standard product improvement—that is, when a firm offers intraconnectivity, it also finds it optimal to reduce price.

If the firms offer interconnectivity, the effect on competition is opposite: the incentive to reduce price

[1] Note that if one only compares the cases of both firms offering intraconnectivity and both firms not offering it, then the value-enhancing effect cancels out (unless the market is not yet fully covered), and only the extra incentives to reduce price remain. Therefore it is much more straightforward to observe that firms could be better off if intraconnectivity does not exist than if it is provided by both firms, but the individual firm's decision on intraconnectivity that would only affect its own product is much more nuanced.

decreases for both firms and each firm benefits from the other firm's higher price. Therefore firms are able to more than recover the value created by interconnectivity and obtain higher profits relative to the case when they do not offer interconnectivity. This result is much more straightforward. The intuition is that interconnectivity weakens price competition by creating complementarity: an increase in one product's installed base also makes the competing product more valuable because the two products now share a single network.[2]

Extending the model to allow for market expansion when prices are lower or when products provide more value, we show that the above results hold as far as competition is strong enough, i.e., when higher value or lower price result mainly in consumers switching which product to buy rather than from consumers hitherto staying out of the market. In addition, the model extension without a fully covered market shows new possibilities in the optimal strategies. When the potential market expansion coefficient increases (i.e., when the category demand is more price elastic), it becomes optimal for a firm to offer intraconnectivity but only if the other firm does not offer intraconnectivity. In other words, intraconnectivity provision by one of the firms decreases the incentive of the other firm to offer intraconnectivity. For markets with even more elastic category demand, each firm may find it optimal to provide intraconnectivity regardless of the intraconnectivity provision of the other firm, but the net effect of both firms providing intraconnectivity is a decreased profit of each of the firms. In other words, the intraconnectivity choice becomes a prisoner's dilemma type game in which a dominant strategy followed by each firm results in lower profits by each. As in the standard prisoner's dilemma game, this is because a firm offering intraconnectivity in this case decreases its competitor's profits more than it increases the first firm's profit. But if the category demand is even more elastic, intraconnectivity provision by both firms may increase industry profits relative to the case when neither firm does. The last result is intuitive because when consumers outside of the market are more important than the consumers marginal in their decision between the two products, the firm's problem is akin to a monopoly problem, and a single-product monopoly would always find it optimal to improve a product unless it is costly to do so.[3]

The above result about undersupply of intraconnectivity in a competitive market can be viewed as consistent with the industry practice. In the absence of industry-wide standards, products that are not specifically designed for interpersonal communication do not usually offer easy connectivity to each other. For example, one could imagine portable electronic devices such as Amazon Kindles, Palm Pilots, or iPods being able to sync to each other. Although a universal connection could infringe on copyright or damage sales, it should not be technologically prohibitive to design the electronic readers to be only able to transfer files obtained for free (e.g., each document that was obtained by Amazon Kindle for a price or special offer could be marked as nontransferable in a system file that cannot be user updated).

Coming back to our first example, the video game console manufacturers did not create networked games and consoles that would allow consoles to be connected through a phone call, even though the connection through a phone line does not seem to be much more complicated than a joystick-to-console connection. In fact, in the above example of video game consoles, limited intraconnectivity through the Internet was introduced only at times when the category had three competitors (entry of Xbox), in which case it could be that the competitive goal of the firm introducing it (Microsoft) was predatory (note that networked computer games existed since the 1970s). At the same time, Xbox was criticized for requiring a broadband Internet connection for its intraconnectivity, thereby severely limiting the number of customers able to use it at its introduction in 2002. Another possible reason for finally offering intraconnectivity consistent with our findings is that intraconnectivity was offered only when it was important to compete with the outside option: personal computers becoming widespread and powerful enough to be considered a good substitute for dedicated game consoles.

Another example from the above industry could be the lack or significant delay in the production of multiplayer versions of many commercial video games. On the other hand, many games freely available online allow multiple players.

Meanwhile, interconnectivity is widespread when it is technologically possible (e.g., between different time-share companies' plans and between different cell phone networks). Our analysis suggests that as long as firms do not pursue a predatory goal, and when the value of the product without the possibility to connect is high enough, firms will tend to underinvest in intraconnectivity but overinvest in and cooperate to offer interconnectivity.

1.1. Literature Review

Our paper is related to the extensive literature on network externalities. This literature has consistently found that positive network externality intensifies

[2] We thank an anonymous reviewer for suggesting this explanation.

[3] Considering the effects of connectivity costs, we also show that intraconnectivity may be overprovided when the per-connection cost is high enough.

competition when entry is not endogenous (e.g., Katz and Shapiro 1985).[4] However, these papers investigate firms' decisions in markets with exogenous network externalities. If firms are able to make decisions that affect network externalities, it is unclear whether the positive network externalities will arise because of firms' independent decisions on creating positive network externalities for their own products similarly to the prisoner's dilemma game. In contrast, we investigate decisions by individual firms that affect network externality, thus endogenizing this characteristic of the marketplace.

The effect of lowering access prices (also known as termination charges) in the telecommunication industry is somewhat similar to the effect of interconnectivity in our paper. Armstrong (1998), Laffont et al. (1998a, b), Carter and Wright (1999), Gans and King (2000), and Calzada and Valetti (2008) analyze the optimal setting of access prices and find that depending on the pricing possibilities to their customers, firms may want to cooperate on setting the access prices to each other either above or below costs. However, in the above, network externalities are created through cost structure (i.e., on the supply side), whereas we explore the product design decisions that are driven by the demand-side rather than the cost-side considerations. In addition, our main emphasis is on the noncooperative intraconnectivity decisions.

Interconnectivity in our paper is also similar to some definitions of compatibility in previous studies in the literature (Katz and Shapiro 1985, 1986, 1992; Farrell and Saloner 1986; Choi 1994; Xie and Sirbu 1995). Whereas we focus on the competitive effects of interconnectivity in a differentiated market, these papers mostly focused on the path of technology adoption and competitor entry (Farrell and Saloner 1986, Katz and Shapiro 1986, Xie and Sirbu 1995) and dynamic profit maximization by a monopolist (Katz and Shapiro 1992, Choi 1994). Katz and Shapiro (1985) derive results about compatibility choice in a competitive industry similar to our results about interconnectivity, but they consider Cournot competition in an undifferentiated product market, whereas we consider Bertrand competition in differentiated product market. Furthermore, our most interesting results are regarding the choice of intraconnectivity. This type of connectivity has not been considered in the existing literature. Note that some literature on product compatibility considered the issue of consumers assembling systems from components of different manufactures (e.g., Matutes and Regibeau 1988, Economides 1989, Einhorn 1992, Denicolo 2000). Although this type of compatibility does not affect network externalities and thus is very different from our definition of interconnectivity, this literature also generally found that compatibility softens price competition.

Existing literature has also explored how value creation may be less valuable to a firm in the presence of competition compared with a monopoly setting if this value creation decreases differentiation among competitors (Banker et al. 2007, Carr 2003, MacDonald and Ryall 2004), and it can even be detrimental if it leads to significantly lower differentiation from the competitor (Brander and Spencer 1983, Roller and Tombak 1990). In contrast, as we have mentioned above, our results do not depend on the effect of firm decisions on product differentiation, because we deliberately assume in the main model that value of intra- and interconnectivity does not correlate with the underlying consumer preferences for the firms. A product feature may also benefit a firm that first introduces it if it has a resource advantage (Brander and Spencer 1983, MacDonald and Ryall 2004, Roller and Tombak 1990) or if the technology reduces market uncertainty, because in that case firms may tend to price as if they are differentiated (Banker et al. 2007). Our paper contributes to this literature by showing how value creation can be detrimental to a firm's profits even when it does not result in lower differentiation from the competitor. Specifically, a firm may be worse off with an intraconnectivity enhancement even when the competitor's products do not have intraconnectivity (i.e., even when intraconnectivity would differentiate this product from the product of the competitor).

There are some parallels between compatibility and switching costs. Although switching costs of locked-in customers decrease competition, a more intense initial price competition can be expected in markets with switching costs (e.g., Klemperer 1987a, b). As a result, the total profits may be either higher or lower. In particular, the total profits may be lower in the presence of switching costs when firms can commit to future prices (von Weizsäcker 1984 and Caminal and Matutes 1990) or when switching costs are explained through product compatibility (Mariñoso 2001), information sharing among firms (Bouckaert and Degryse 2004), or consumer learning (Villas-Boas 2004, 2006; Doganoglu 2010). Although the empirical research on telephone number portability (Shi et al. 2006,

[4] Similar results have been shown in infinite-period (e.g., Cabral 2011) and continuous-time (e.g., Driskill 2007) models, although the main emphasis of dynamic models is mostly on entry–exit (e.g., Fudenberg and Tirole 2000), market share dynamics (e.g., Mitchell and Skrzypacz 2006, Markovich 2008, Markovich and Moenius 2009, Doraszelski et al. 2009, Cabral 2011), or technology adoption (e.g., Katz and Shapiro 1986, Farrell and Saloner 1986). Recent literature also extended the consideration of the effects of network externalities to channel coordination (Li 2005), product strategies (Basu et al. 2003 and Sun et al. 2004), cross-market network competition (Chen and Xie 2007), and bundling (Prasad et al. 2010). Network-based pricing (e.g., Shi 2004) may also create network externalities.

Viard 2007, Park 2011) found that portability (i.e., lower switching costs) increases competition, Dubé et al. (2009) find empirical support for their prediction that profits could be U-shaped as a function of switching costs.[5]

The remainder of this paper is organized as follows. In §2, we introduce a duopoly model in which consumers derive utility from both the product itself and connecting with other consumers. This model assumes that consumer product valuation is high enough so that the market ends up being fully covered regardless of the firms' connectivity choices. Section 3 analyzes the model and derives the optimal intra- and interconnectivity strategies. Section 4 extends the model to allow for market expansion. Section 5 considers the implications of the costs of connectivity. Section 6 concludes with a further discussion of the results, their robustness, venues for empirical testing of the predictions, and managerial implications. The online appendix (at http://dx.doi.org/10.1287/mksc.1120.0705) relaxes and discusses some technical conditions on the parameters, considers consumer heterogeneity in the value of connectivity, considers the possible effect of connectivity on differentiation, considers alternative pricing mechanisms where firms set a price for the product only and when they can separately charge for the product as well as for a connection to other consumers through this product, and allows the consumer connection time to be affected by the price of connections.

2. The Model with a Fully Covered Market

In the manner of Hotelling (1929), a unit mass of consumers has ideal points distributed uniformly on a line segment, $[0, 1]$. Two firms, labeled Firm 1 and Firm 2, are located at the ends of the segment and produce one product each. We will use the terms "consumer location" and "location of the consumer's ideal point" interchangeably, as the former is shorter but the latter is more precise.

2.1. Consumers' Preferences and Decisions

Consumers have value for one product only. The utility of consumer i for a product located at a distance d_i away from her ideal point is $V - td_i$, where V and t are parameters. In addition to the utility of the product itself, a consumer would derive utility from connecting the product to products of other consumers if the firm allows this possibility. This additional utility increases in the number of consumers a given consumer is able to connect to. For simplicity, we assume a linear dependence but allow the value to depend on whether the connection is between the products of the same or different firms, because the functionality of such connections could be different. Hence, if firm j ($j = 1, 2$) provides intraconnectivity of its products, its customers receive an additional utility of $\theta_C \cdot M_j$, where M_j is the mass of customers of firm j and θ_C is a parameter. Furthermore, if product j has both intra- and interconnectivity, then the consumer valuation for the product additionally increases by $\theta_I \cdot M_{3-j}$, where M_{3-j} is the mass of consumers of the other firm and θ_I is the interconnectivity value parameter. Thus, a consumer purchasing the product of firm j receives the net utility of

$$U_{ij} = V - td_{ij} + \delta_C \cdot \theta_C M_j + \delta_I \cdot \theta_I M_{3-j} - f_j, \qquad (1)$$

where δ_C and δ_I are the indicators of the presence of intra- and interconnectivity, respectively; d_{ij} is the distance from the consumer's ideal point to the firm's location; and f_j is the price of Firm j's product. Note that we assume that offering intra- or interconnectivity does not affect underlying preferences consumers have for potential product attributes; i.e., the parameters V, t, θ_C and θ_I remain unchanged. However, offering intraconnectivity or interconnectivity changes the product itself and therefore affects consumer preferences toward products. Thus, we do not assume that a particular way of offering intra- or interconnectivity could affect product differentiation, but rather allow the possible change in product differentiation to be endogenous.

We assume that the consumer value parameter V is high enough relative to t and the equilibrium price charged for the product, so that every consumer will end up purchasing either one of the products regardless of the connectivity choice. We will call this outcome a fully covered market. Stated formally, the sufficient condition for this outcome is $V > 3t/2$. For the uniqueness of equilibrium, we also need to assume that $t > \theta_C$; i.e., the amount of differentiation between the products of the two firms is greater than the value of intraconnectivity.[6]

2.2. Firms' Decisions and Profits

Firms have equal and constant marginal cost of production, which we normalized to zero, and no costs of intra- and interconnectivity provision.[7]

[5] Another factor to consider in profitability of switching costs in a competitive environment is the interaction of switching costs and advertising. For example, Anderson et al. (2010) find empirically that consumer switching costs may increase positive spillovers of advertising across firms. It would be interesting to further consider how asymmetry in network externalities (see, e.g., Tucker and Zhang 2010) could also affect optimal strategies.

[6] For a discussion of the equilibrium when this assumption does not hold, see the online appendix, which also shows robustness of the results with respect to consumer heterogeneity in θ and considers the possibility that a consumer's value of connectivity is correlated with the consumer's value of the product.

[7] In §5, we also analyze the implications of positive costs of connectivity provision.

We will consider the following two possibilities in the firms' product design decisions: (a) to offer intraconnectivity or not, when interconnectivity is not a decision variable or not technologically possible; and (b) to offer interconnectivity or not, when intraconnectivity already exists for both products. We will refer to the first as the intraconnectivity game and the second as the interconnectivity game. Because it is unlikely that interconnectivity can exist if one of the firms does not allow it, we assume that if either of the firms decides not to allow interconnectivity, interconnectivity will not exist. However, allowing interconnectivity to be an individual decision does not change the main results.

Besides specifying whether to offer intraconnectivity or interconnectivity for their products, firms also choose product prices, f_j $(j = 1, 2)$.

2.3. Timing

The game sequence is as follows. When interconnectivity is technologically infeasible, the firms simultaneously decide whether to offer intraconnectivity, and then they simultaneously decide on product price f. Consumers then make their purchase decisions. When intraconnectivity already exists for both products and interconnectivity is the decision variable, firms simultaneously decide whether to offer interconnectivity or not, with interconnectivity created if and only if both firms have decided to offer it. Then the firms simultaneously decide on product prices, and finally, the consumers make purchase decisions. This sequential product–price decision timeline is crucial for the results to hold and is a standard assumption when modeling product and price decisions (Moorthy 1988, Desai 2001, Kuksov 2004, Syam et al. 2005) as a result of product decisions being more difficult to change than pricing and, therefore, each firm being able to condition its price decision on its competitor's product choice. Firms maximize their profits, and consumers maximize their utilities net of price paid. Because it is a multistage game, we use subgame-perfect Nash equilibrium as the solution concept. The following section analyzes the model and includes some derivations that could be useful for a better understanding of the intuition, and the appendix contains the proofs.

3. Analysis of the Model with Fully Covered Market

3.1. Intraconnectivity

We start by deriving the result for the case when intraconnectivity is a decision variable and interconnectivity is technologically infeasible. This case is important for two reasons. First, the expected outcomes in this game may affect firms' decisions to offer interconnectivity if it is also technologically feasible. Second, if interconnectivity is technologically not feasible, this case becomes the complete game. For example, in the computer game industry, two games cannot be interconnected if they are different (e.g., consumers playing chess games cannot be interconnected with consumers playing football games).

Let C and N represent the decisions to offer or not to offer intraconnectivity, respectively. Using backward induction, we first consider consumer product choice, given prices. Let M be the demand for Firm 1. The demand of the other firm will then be $1 - M$.[8] Note that because the market size is normalized to 1, when the market is fully covered, a firm's demand equals its market share. Hence we will use these terms interchangeably.

If each firm has a positive market share, market shares are derived from the location of the indifferent consumer on the Hotelling line as follows:

(a) In an (N, N) subgame,

$$M = \frac{t + f_2 - f_1}{2t} \quad \text{and} \quad 1 - M = \frac{t + f_1 - f_2}{2t}, \tag{2}$$

unless these expressions result in $M < 0$, in which case the actual market share of Firm 1 is $M = 0$. Likewise, if the solution is $M > 1$, then the actual market share of Firm 1 is $M = 1$.

(b) In a (C, N) subgame,

$$M = \frac{t + f_2 - f_1 + M^e\theta_C}{2t} \quad \text{and} \quad 1 - M = \frac{t + f_1 - f_2 - M^e\theta_C}{2t}, \tag{3}$$

where M^e is the consumer expectation of the equilibrium market share of Firm 1.

(c) In a (C, C) subgame,

$$M = \frac{t + f_2 - f_1 + M^e\theta_C - (1 - M^e)\theta_C}{2t} \quad \text{and} \quad 1 - M = \frac{t + f_1 - f_2 + (1 - M^e)\theta_C - M^e\theta_C}{2t}. \tag{4}$$

To solve (b) and (c), note that the Nash equilibrium concept requires rational expectations; i.e., the expected-by-consumers market share of Firm 1, M^e, is equal to the actual market share M. Hence, substituting M^e for M in Equations (3) and (4) and solving for M^e, we obtain the internal solution $(0 < M < 1)$ equilibrium market shares in a (C, N) subgame as

$$M = M^e = \frac{t + f_2 - f_1}{2t - \theta_C} \quad \text{and} \quad 1 - M = 1 - M^e = \frac{t - \theta_C + f_1 - f_2}{2t - \theta_C}, \tag{5}$$

[8] After solving for equilibria in prices in each of the four intraconnectivity choice subgames, we check what condition on V results in the full coverage of the market in all subgames.

whenever both are nonnegative, and in a (C, C) subgame as

$$M = M^e = \frac{t-\theta_C+f_2-f_1}{2(t-\theta_C)} \quad \text{and} \qquad (6)$$
$$1-M = 1-M^e = \frac{t-\theta_C+f_1-f_2}{2(t-\theta_C)},$$

again, whenever both are nonnegative.

In addition, one needs to check the possibility of corner solutions. If substituting $M^e = 0$ in Equation (3) or Equation (4) results in $M \le 0$, then $M = 0$ is also an equilibrium outcome of the corresponding subgame. Likewise, if substituting $M^e = 1$ in Equation (3) or Equation (4) results in $M \ge 1$, then $M = 1$ is also an equilibrium outcome of the corresponding subgame.

For the (C, N) subgame, the former implies that $M = 0$ is an equilibrium outcome when $f_2 < f_1 - t$. The latter implies that $M = 1$ is an equilibrium outcome when $f_1 < f_2 + \theta_C - t$. Therefore, when $\theta_C > 2t$, both $M = 0$ and $M = 1$ could be equilibria (for some f's), and Equation (5) may also state another (internal) equilibrium as well. It is important to note that this is not a contradiction but rather that Equation (3) with boundary conditions has multiple equilibria when $\theta_C > 2t$. Since we have assumed $\theta_C < t$, Equation (5) defines the unique equilibrium when it results in $M \in [0, 1]$; otherwise, the boundary solution is the unique (consumer choice) equilibrium, given prices.

The same consideration of the boundary possibilities applies in a (C, C) subgame. Here, we have that the equilibrium is unique when $t - \theta_C > 0$, and multiple equilibria can exist for some pricing choices when $t - \theta_C < 0$. In particular, $f_1 = f_2$ would result in three equilibria: $M = 0$, $1/2$, and 1. This is why we need the assumption $t - \theta_C > 0$.

Given the above demand functions, we can write the first-order conditions on the profit functions as

$$\frac{\partial \Pi_1}{\partial f_1} = \frac{t+f_2-2f_1}{2t} = 0 \quad \text{and} \qquad (7)$$
$$\frac{\partial \Pi_2}{\partial f_2} = \frac{t+f_1-2f_2}{2t} = 0 \quad \text{in an } (N, N) \text{ subgame},$$

$$\frac{\partial \Pi_1}{\partial f_1} = \frac{t+f_2-2f_1}{2t-\theta_C} = 0 \quad \text{and} \qquad (8)$$
$$\frac{\partial \Pi_2}{\partial f_2} = \frac{t-\theta_C+f_1-2f_2}{2t-\theta_C} = 0 \quad \text{in a } (C, N) \text{ subgame},$$

$$\frac{\partial \Pi_1}{\partial f_1} = \frac{t-\theta_C+f_2-2f_1}{2(t-\theta_C)} = 0 \quad \text{and}$$
$$\frac{\partial \Pi_2}{\partial f_2} = \frac{t-\theta_C+f_1-2f_2}{2(t-\theta_C)} = 0 \quad \text{in a } (C, C) \text{ subgame}. \qquad (9)$$

Solving these, we obtain the following equilibrium prices, sales, and profits (see the appendix for the proof that the solutions to the first-order conditions are in fact globally optimal, i.e., constitute an equilibrium):

(a) In an (N, N) subgame,

$$f_1^* = f_2^* = t \text{ (prices)}, \quad M_1^* = M_2^* = \frac{1}{2} \quad \text{(sales)}, \qquad (10)$$
$$\text{and} \quad \Pi_1^* = \Pi_2^* = \frac{t}{2} \text{ (profits)}.$$

(b) In a (C, N) subgame,

$$f_1^* = (3t-\theta_C)/3 \quad \text{and} \quad f_2^* = (3t-2\theta_C)/3 \text{ (prices)},$$
$$M_1^* = (3t-\theta_C)/(6t-3\theta_C) \quad \text{and}$$
$$M_2^* = (3t-2\theta_C)/(6t-3\theta_C) \text{ (sales)}, \qquad (11)$$
$$\Pi_1^* = (3t-\theta_C)^2/(9(2t-\theta_C)) \quad \text{and}$$
$$\Pi_2^* = (3t-2\theta_C)^2/(9(2t-\theta_C)) \text{ (profits)}.$$

(c) In a (C, C) subgame,

$$f_1^* = f_2^* = t-\theta_C \text{ (prices)}, \quad M_1^* = M_2^* = \frac{1}{2} \text{ (sales)}, \qquad (12)$$
$$\Pi_1^* = \Pi_2^* = \frac{t-\theta_C}{2} \text{ (profits)}.$$

The above analysis leads to the following result about the optimal choice of intraconnectivity.

Proposition 1. *It is optimal for each firm not to offer intraconnectivity regardless of whether the other firm offers intraconnectivity.*

To better understand the mechanism of why offering intraconnectivity decreases the firm's profits, let us examine the first-order conditions in Equations (7)–(9). Comparing Equation (7) to Equation (8), one can see that, keeping the price and the intraconnectivity provision of the competing firm constant, when a firm offers intraconnectivity, the numerator of its first-order conditions on price does not change. This means that, keeping the competing firm's decisions constant, a firm introducing intraconnectivity would not find it beneficial to change its price. In other words, the direct effect of offering intraconnectivity on price is a wash (neither positive nor negative). This is due to the two opposing incentives—the incentive to raise the price because the consumer value increased and the incentive to decrease the price to enhance the value and increase sales further—exactly canceling each other out. On the other hand, the effect of a firm introducing intraconnectivity on the numerator of the first-order conditions of the competing firm is negative (the numerator gets θ_C subtracted). This is because a firm offering intraconnectivity will draw market share from the competitor. Then, the competitor, now having a lower market share, is more willing to sacrifice the margin on the existing sales to attract new sales. Therefore, starting from the equilibrium prices of (N, N) or (C, N), when a firm introduces intraconnectivity, the competitor will find it optimal to reduce price. This, in turn, means that the firm introducing intraconnectivity has an incentive to reduce price as well (because the competitor's price enters its first-order conditions with a positive coefficient). This is the strategic effect of offering intraconnectivity on prices. Because the direct effect is zero and the strategic effect is negative, intraconnectivity decreases prices.

Proposition 1 implies that intraconnectivity as a product feature may be detrimental to the firm although it increases the consumer value. The reason that not offering intraconnectivity is the dominant strategy for each firm and not just an equilibrium outcome is that when a firm offers intraconnectivity, the firm creates positive network externality for its product regardless of the other firm's decision on intraconnectivity. Therefore the firm has a stronger incentive to increase market share, i.e., to reduce price. The other firm anticipates this and finds it optimal to respond with a lower price as well. Ensuing price competition erodes profits of both firms so much that it negates the benefit the first firm is able to obtain from improving its product. In other words, the firm offering intraconnectivity turns out to be unable to extract any extra surplus from the consumers because of increased competition. Note that this result holds even given the assumption that intraconnectivity (and connections) is completely costless to the firm.

Note that it is important for the above arguments that the market is fully covered, and the additional demand a firm may obtain from its actions is coming from the market share of the other firm rather than from an expansion of aggregate demand. Of course, this result is robust to some aggregate demand expansion in response to lower prices, but sufficiently strong aggregate demand expansion would invalidate the above result even in the presence of competition (see §4).

3.2. Interconnectivity

Suppose intraconnectivity is already a part of each firm's product strategy; will firms then benefit from providing interconnectivity as well? We call this case the interconnectivity game. Recall that when one of the firms does not offer interconnectivity, interconnectivity is not offered, and we have the (C, C) subgame already considered above. When both firms offer intra- and interconnectivity, which we will denote by (IC, IC), the solution is similar to that of the (C, C) subgame. Specifically, given prices, the market share of Firm 1 becomes

$$M = \frac{t+\theta_I-\theta_C+f_2-f-2M^e(\theta_I-\theta_C)}{2t}, \tag{13}$$

where M^e again denotes the consumer expected market share of Firm 1. Using the rational expectations condition $M = M^e$, we derive the (consumer choice subgame) equilibrium market shares as

$$M = \frac{t+\theta_I-\theta_C+f_2-f_1}{2(t+\theta_I-\theta_C)} \quad \text{and} \\ 1-M = \frac{t+\theta_I-\theta_C+f_1-f_2}{2(t+\theta_I-\theta_C)}. \tag{14}$$

Note that unlike in the intraconnectivity game, we do not have to make an assumption about the relative value of θ_I to have a unique equilibrium in the consumer choice subgame. This is because the higher the value of θ_I, the more difficult it is for a firm to dominate the market.[9] The first-order conditions in this case have a unique solution, $f_1^* = f_2^* = t + \theta_I - \theta_C$, resulting in the equilibrium profits $\Pi_1^* = \Pi_2^* = (t+\theta_I-\theta_C)/2$. Thus, we obtain the following.

Proposition 2. *Offering interconnectivity increases profits. Furthermore, the benefit of interconnectivity to firms is higher than the total consumer value created by interconnectivity.*

Proposition 2 indicates that interconnectivity may ameliorate the negative impact of intraconnectivity on firm profits. Intuitively, this is because with interconnectivity, the value that consumers assign to a product *increases* with the number of customers who use the *competing* product, which is opposite to the positive network externality effect of intraconnectivity. When the firms add interconnectivity to intraconnectivity, the market structure changes back from one with (positive) network externality to one without. The incentive for firms to increase market share by competing aggressively on price is no longer as strong as when only intraconnectivity is present. Thus, interconnectivity reduces competition and increases firms' profits.

The result above is consistent with the behavior of time-share companies: they allow their customers to exchange time-share weeks or points not only within the same firm's network but also across different firms' networks. We can see now that firms are offering such interconnectivity features not only because they want to offer their customers more value but because they also want to reduce market competition.

To see that it may be optimal for firms to offer interconnectivity even when the costs are higher than the consumer value, stated formally, observe that when interconnectivity is provided, each firm's profits increase by $\theta_I/2$, and the total consumer value created

[9] Technically speaking, the relevant condition similar to "θ_C small enough" is that θ_I is not too far negative.

is $\theta_I/4$ per firm. The intuition is that just as intraconnectivity increases price competition by providing greater incentive for a firm to compete for market share, the effect of interconnectivity is the opposite because it provides incentive for a firm to value the sales of its competitor, thereby reducing the incentive to compete for market share.

Just as in the intraconnectivity case, the results about interconnectivity apply if the firms are profit maximizing, assuming that their actions will not lead to entry or exit. A dominant firm could instead hope that if it refrains from interconnectivity, the lower profits for each company would lead to an exit of weaker competitors.

4. Model Extension with a Not Fully Covered Market

In this section, we consider what would happen if product improvement would increase sales not only through consumers switching from one firm to the other but also through some market expansion. In other words, we consider the case when without connectivity, the market is not fully covered. Note that the standard Hotelling model with firms at the ends of the interval is not well suited for this analysis because either firms do not compete at all (if V is small enough) or, in the intermediate range of V, at least one of the subgames has multiple equilibria, as is the case for the intermediate range of V in the standard Hotelling model. This does not allow us to predict what happens in that range of V.

To be able to consider what would happen in the intermediate case between a monopoly and the fully covered market, let us consider the following model extension. Let us assume that besides the consumers on the interval $[0, 1]$ distributed with unit density, there are also consumers with ideal points left of 0 and right of 1 infinitely extended with density m. Technically speaking, this assumption implies an infinite mass of potential consumers. However, there is a finite mass of consumers who are interested in either product at a nonnegative price. The extra consumers to either side of the interval between the firms ensure that when a firm reduces price, its sales increase not only because of brand switching (consumers between the firms) but also because of the category expansion (consumers to the left of Firm 1 or to the right of Firm 2). To keep the number of parameters manageable, let us assume that the cost of connectivity is zero and consider the intraconnectivity game. Note that the model considered in the previous sections is a special case of this model ($m = 0$). As m increases, lowering prices or offering either type of connectivity leads to a larger market expansion.

To ensure nontrivial competition in this model, assume that $V > V_{\min} = 3t/2 - mt/(1+m)$. If this condition is not satisfied, there are consumers between firms who do not buy either product when intraconnectivity is not offered. For simplicity, also assume that $m < 1$.[10] In addition, similar to the standard Hotelling model with internal locations of the firms (see, e.g., d'Aspremont et al. 1979), this model does not have a pure-strategy equilibrium when the mass of potential consumers on either side of each firm is high enough. Because in our infinite line model the market share of sales from the outside of the unit interval increases in V, to make sure that the equilibrium is in pure strategies, we must assume that V is not too high. It turns out that the most restrictive condition on V ensuring pure-strategy equilibrium comes from the case when both firms offer intraconnectivity and is quite algebraically complex. We will therefore simply refer to it as $V < V_{\max}$ and assume that $V \in [V_{\min}, V_{\max}]$. It turns out that the range $[V_{\min}, V_{\max}]$ is nonempty if and only if θ_C is not too high. We denote this critical value of θ_C by $\theta_{\max}(t)$. Figure 1 shows a graph of this boundary condition.

To analyze this extension, consider the following. The addition of the set of consumers outside of the $[0, 1]$ interval means that given prices f_1 and f_2, Firm j will gain $(V + \delta_{jC} \cdot M_j \theta_C - f_j)m$ of these additional consumers, where δ_{jC} is the dummy variable reflecting whether Firm j offered intraconnectivity and M_j is the (expected by the consumers) sales of Firm j. Note that, unlike in the main model, M_j is no longer equal to the market share, because the sum of demands is higher than 1. The indifferent consumer's location x is derived from the indifference equation

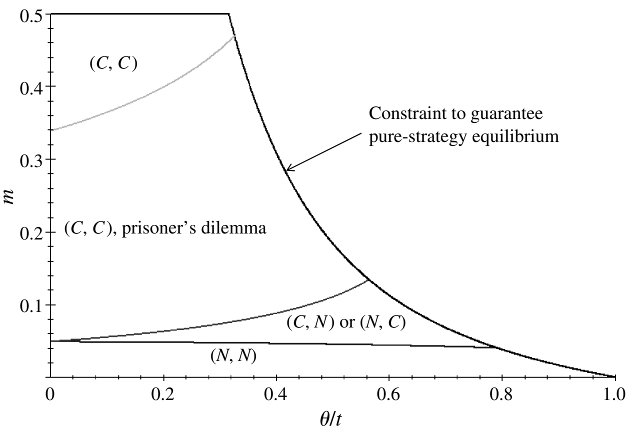
$$V - tx + \delta_1 \theta_C M_1 - f_1 = V - t(1-x) + \delta_2 \theta_C M_2 - f_2, \quad (15)$$

where, in equilibrium, $M_1 = x + (V + \delta_1 M_1 \theta_C - f_j)m$ and $M_2 = 1 - x + (V + \delta_2 M_2 \theta_C - f_j)m$. Again, this holds as long as all consumers on the interval $[0, 1]$ buy, which turns out to happen when $V > V_{\min}$. Solving the above equations simultaneously, we determine the equilibrium demand of the consumer choice subgame. The rest of the solution is standard and follows from the first-order conditions.[11]

[10] This assumption is not strictly necessary, but it avoids the possibility that profit functions have an upward kink, thus simplifying the solution process.

[11] The single complication is that one needs to confirm that a firm will not find it optimal to deviate to a price low enough to possibly capture consumers on the other side of the competing firm. This condition needs to be checked because although the profit function of the firm is concave everywhere else, it discontinuously increases at this point. The condition that such undercutting cannot be optimal in neither of the connectivity choice subgames results in the condition $V < V_{\max}$, where $V_{\max}$ is a solution of a quadratic equation.

Figure 1 Graph of Regions of Different Equilibria



Note. Horizontal axis: θ_C/t; vertical axis: m.

Proposition 3. *For sufficiently small m, it is optimal for each firm not to offer intraconnectivity regardless of the other firm's choice.*[12] *For intermediate m, it is optimal for a firm to offer intraconnectivity if and only if the other firm does not offer it. For sufficiently high m, it is strictly optimal for each firm to offer intraconnectivity regardless of the other firm's choice.*[13] *Furthermore, (C, C) is a prisoner's dilemma equilibrium outcome for some m. The equilibrium outcomes are depicted in Figure* 1.

To interpret the numerical values of m in Figure 1, it could be useful to think about what a particular value of m implies about the category versus brand price sensitivity. For this purpose, note the implication that when $m = 0.045$ and $\theta_C/t = 1/2$, then 22% of the additional sales as a result of a price decrease would come from market expansion and 78% from brand switching. Thus, as long as less than 22% of new sales are coming from market expansion, the model predicts that neither firm would offer intraconnectivity. Note that the equilibrium outcomes can be plotted in just two dimensions, m and θ_C/t, because the order of the equilibrium profits in the pricing subgames does not depend on V. To complete the description of possible equilibrium outcomes, note that if (C, N) is an equilibrium, then (N, C) is also an equilibrium, and there is an equilibrium in mixed strategies over N and C. On the other hand, when either (N, N) or (C, C) is an equilibrium, the equilibrium is unique.

Thus, this extension shows that the main results about intraconnectivity are robust to small market expansion effect and also show the possibility of asymmetric equilibria arising from a symmetric setup in the intraconnectivity game. It also shows how market expansion effect can actually be bad for the firms, as it results in the prisoner's dilemma that more than negates the additional profits from extra consumers (Cabral and Villas-Boas 2005 refer to such situations as Bertrand supertraps). In particular, this gives us an example of a model where adding consumers to the market reduces profits of all firms. In fact, it turns out that there are m and V such that (C, C) is the unique equilibrium outcome with profits lower not only than in the case of (N, N) but also lower than if consumers to the left and right of the interval [0, 1] did not exist (in which case, (N, N) is the unique equilibrium outcome).

In some product categories, a product without intraconnectivity or interconnectivity has very low utility to consumers. Therefore, if such products do not have any connectivity, then the market is not fully covered, even when the product prices are zero. For example, a mobile phone without (consumer-to-consumer) connectivity may still be used (e.g., to call 911), but sales of such a device would be much lower than the sales of current cell phones. Therefore, cell phones cannot be considered as an example for the case of a fully covered market (even though after offering intra- and interconnectivity, the market coverage may be close to full). Also, in such product categories, if interconnectivity is technologically not possible, intraconnectivity will still be offered. For example, in the industry of role-playing computer games, interconnectivity is impossible (because different games have different stories), but intraconnectivity is still offered because otherwise, the games would not be able to present an entertaining story.

5. Costs of Connectivity

Offering intraconnectivity and/or interconnectivity may be costly to the firms. This cost may be fixed or variable, and the variable part of the cost may be either a variable cost of product modification (i.e., a per-product cost) or a variable cost of establishing and maintaining connections (i.e., a per-connection cost).

Fixed costs are most likely costs a company introducing connectivity could be expected to incur—either because of fixed costs of production modification or a fixed cost of the network over which customers connect. It is also the easiest to analyze. Because offering intraconnectivity was a dominated strategy even in the absence of fixed costs and fixed costs are not relevant for pricing, offering intraconnectivity would be a dominated strategy in the presence of fixed costs as well. On the other hand, because

[12] For example, when $\theta_C/t = 1/2$, (N, N) is the equilibrium if m is such that at most 22% of a firm's demand increase as a result of offering connectivity is coming from the consumers who would buy neither product otherwise.

[13] For some values of θ_C/t, the "intermediate" and "sufficiently high" m do not exist given the range restriction needed for a pure-strategy equilibrium. But all these possibilities exist when $\theta_C/t < 0.3$.

interconnectivity is beneficial in the absence of fixed costs, it will still be beneficial when fixed costs are not too high. An interesting observation we made in §3 is that the benefit of interconnectivity to firms exceeds that of consumers. Therefore, interconnectivity could be offered even when its fixed costs exceed the consumer benefit.

Another possibility is per-product costs of allowing connectivity. These costs would be incurred if connectivity requires adding a physical component to the product, such as a modem or a radio, infrared, or Bluetooth transmitter. Such costs would have a positive effect on prices. The direct effect of a higher variable cost is negative on profits, whereas strategic effect is positive (because the competing firm would also increase price expecting the focal firm to increase price). As in the standard Hotelling model, the total effect is negative. Thus, intraconnectivity would still be a dominant strategy, and the benefit of interconnectivity could be reduced. We again obtain that the effect of such costs is as expected.

Could connectivity costs change the results in a less obvious way? It turns out that per-connection costs could reverse the results. To see this, assume that any firm offering connectivity incurs a constant per-connection cost (which could be different for the two types of connections) so that the connection cost increases linearly with the number of possible connections. Then firm j's cost of allowing its customers to connect to each other will end up being $c_C M_j^2$, and the cost to allow its customers to connect to the competitor's customers (if the competitor likewise allows) will end up being $c_I M_j^2$. Thus, the profit Π_j of firm j when neither intraconnectivity nor interconnectivity is allowed, when intraconnectivity alone is provided, and when both are provided is $M_j f_j$, $M_j f_j - c_C M_j^2$, and $M_j f_j - c_C M_j^2 - c_I M_j M_{3-j}$, respectively. As before, we require the market to be fully covered in equilibrium of any connectivity choice subgames, which means that V needs to be high enough relative to the product differentiation and the costs. Specifically, we assume that $V > 2t + c$ and continue to assume that $\theta_C < t$. We then obtain the following result.

Proposition 4. *Let $c_C^*(\theta_C, t)$ be the unique positive solution for c of*

$$4c^3 - 4\theta_C c^2 - (6t + \theta_C)(2t - \theta_C)c - 2\theta_C(3t - \theta_C)(2t - \theta_C) = 0. \tag{16}$$

If $c_C < c_C^*(\theta_C, t)$, then not offering intraconnectivity is strictly optimal for each firm regardless of the other firm's intraconnectivity decision. Furthermore, $c_C^*(\theta_C, t) > \theta_C$. On the other hand, when $c_C \geq c_C^*(\theta_C, t)$, each firm finds it optimal to offer intraconnectivity if and only if the other firm offers it. In this case, both (N, N) and (C, C) are equilibria and (C, C) is the Pareto-optimal one.

Note that when $\theta_C > c_C$, it is socially optimal for each firm to offer intraconnectivity. Therefore, Proposition 4 indicates that neither firm wants to offer intraconnectivity when it is socially optimal to offer it, but the firm could benefit from offering it when it is not cost justified.

To better understand the intuition for the effect of costs on the incentives to provide intraconnectivity, it may be useful to discuss how costs enter the first-order conditions on price. Because the costs enter the first-order conditions on price with a positive sign, greater costs provide an extra incentive for a firm to increase price when it introduces intraconnectivity. Recall that without costs, the direct effect of intraconnectivity on prices was zero. Therefore with positive costs, the effect will be positive. The strategic effect may still be negative but not as much as when costs are high, because although the competitor now may expect to lose market share as a result of the first firm's product improvement, it may not lose as much market share as a result of the first firm's price increase. In fact, when the costs of intraconnectivity are very large, the strategic effect becomes positive, as the firm introducing intraconnectivity virtually commits itself to limit its market share to keep the per-product costs down (note that this is not so when connectivity costs are per product). Because committing to a smaller market share could be beneficial in a competitive environment, introducing a very costly intraconnectivity may be used as a marketing strategy to reduce competition. Put another way, the choice of a costly intraconnectivity technology is a commitment or a signal to the competitor that one will not be aggressive on price.

Coming back to the interconnectivity choice, one can show that its implications also reverse when interconnectivity comes at a high enough per-connection cost. Specifically, a firm finds it optimal to adopt interconnectivity if and only if $c_I < 2\theta_I$. Note that since the per-connection benefit from interconnectivity is θ_I, competing firms could benefit from interconnectivity even when it is not cost justified.

6. Discussion and Conclusion

In this paper, we modeled firms' intra- and interconnectivity decisions and their effects on the competitive firms' pricing decisions. We analyzed two cases: whether intraconnectivity should be offered when interconnectivity is not possible and whether interconnectivity should be offered when intraconnectivity is already in place. The main results are that firms would not offer intraconnectivity when offering it is socially beneficial. On the other hand, interconnectivity will be offered when it is socially beneficial, but because of a price increase that more than offsets the consumer benefit of interconnectivity, interconnectivity ends up reducing consumer surplus. Technically speaking, there are two more possibilities of connectivity decisions within the model considered: provision of intraconnectivity when interconnectivity already exists and providing interconnectivity when intraconnectivity does not exist. One could also consider the possibility that both of these decisions need to be made simultaneously. It is easy to verify that the implications of the main model easily extend to these cases: providing intraconnectivity could reduce profits regardless of whether interconnectivity is provided, and providing interconnectivity even at a cost exceeding consumer value could be profitable regardless of intraconnectivity provision.

Offering intra- and interconnectivity has two effects on the market: the direct value creation effect and the strategic effect on competition. The interrelation of these two effects determines what the profit-maximizing decision is. Intraconnectivity generates extra value to consumers. Such value creation effect benefits both the consumers and the firms. However, intraconnectivity also generates positive network externality and makes firms compete more severely for consumers. This is the strategic effect. In a fully covered market, firms can only gain market share from each other rather than from expanding the category by creating more value to the consumers. Therefore intraconnectivity often may have a detrimental effect on profits.[14] On the other hand, interconnectivity not only has a positive value creation effect but also has a positive strategic effect; i.e., it decreases the competitive level. The later effect works together with the value creation effect to increase firms' profits. Furthermore, the effect of interconnectivity on the network externality results in the ability of the firms to extract more of consumer surplus than the consumer benefit of interconnectivity. Thus the net-of-price effect of offering interconnectivity on consumer surplus is negative.

Although throughout the paper we assumed that product sales are the sole revenue source of the firms, an increasing number of technology products adapt multiple-revenue source strategy. In particular, additional revenue may come from advertising. To see how such a possibility would impact the results, let us consider the following model modification. In addition to product sales, assume that the firm places a certain number of ads for each product and charges advertisers per placed ad. Assume also an exogenous advertising rate given some optimal amount of ads per product, presumably coming from the best solution to the trade-off between advertising revenue and degrading the quality of user experience. As a result, each firm receives revenue (profit) a per product sold in addition to the product sales revenue. We then assume that V denotes the value of the product with advertising it. One can then derive that as long as the competitive prices in the main model remained above a or if prices are not bounded by zero from below,[15] the profits conditional on connectivity provision remain exactly the same in all cases. This is because the additional advertising revenue is competed away through prices. Therefore, all results hold. On the other hand, if advertising revenue is high enough and prices are not allowed to be negative, the strategic effect on prices starts to disappear (as the zero price constraint becomes binding). The result is then that offering intraconnectivity becomes beneficial for each firm—more so if the competitor offers intraconnectivity. Therefore, as advertising revenue increases, both firms would start to offer intraconnectivity.

The online appendix provides a number of other model extensions and discussions of the assumptions made, argues for the robustness of the above results, and suggests some boundary conditions. Specifically, the above results are robust to a considerable range of consumer heterogeneity that is uncorrelated with consumer preference for the products themselves and when firms can charge price per-connection and for connection time, in addition to the per-product price. Because the results are driven by dominant strategies, they are also robust to asymmetric cost structure. Some of the boundary conditions for our results to hold are that intraconnectivity should not considerably increase the market size and that if consumers are heterogeneous in their valuations for intraconnectivity, the preference for intraconnectivity should not be strongly correlated with consumer preference for the product itself. In addition, we assumed that the values of intra- and interconnectivity are linear in sales. Although we do not need the exact linear functional shape, what we need is that at the equilibrium sales, the value increase from intraconnectivity as a result of the increase in sales should not be negligible. In other words, the results require that the benefit

[14] Note that because the result is due to the effect of the decision on product-specific network externality, it is applicable to other decisions of the firm that affect network externality and not just technological decisions on connectivity. For example, word-of-mouth effects result in network externalities. Therefore, when customer segments differ in how much word-of-mouth influences choice behavior (e.g., as Manchanda et al. 2008 estimate for physicians affiliated with small versus large clinics), targeting different market segments may result in a different magnitude of the product-specific network externality.

[15] A possible interpretation of negative prices could be that the product is free, and in addition, the firm offers extra product features valuable to consumers and costly to the firm. For example, Sun and Zhu (2011) show some empirical evidence that allowing ad revenue leads to bloggers improving the quality of their blogs.

of intraconnectivity should not be too concave in the product sales.

The most striking prediction of the model is that in a competitive industry, intraconnectivity sometimes would not be offered even if it has negligible costs to the firm and is valued by all consumers. Any example of such an outcome faces at least two serious challenges. First, how do we know that the connectivity is technologically feasible and not prohibitively costly if it has not been implemented? Second, how do we know the feature would be valued by consumers if it has never been offered? After all, most new products fail, which suggests that even industry experts are not able to predict the demand for a product that did not exist before (even if it is only a slight improvement or even repositioning). For example, introducing a car with a radio able to broadcast over a short range (say, 50 yards) to similarly equipped cars should be technologically feasible and not very expensive. After all, relatively cheap walkie-talkies existed for a very long time and have a greater range. Such innovation is not offered but could be valued by consumers who could entertain themselves by making remarks to nearby cars while on a long drive, who would value the ability to ask for directions, or who would pass information on why the traffic ahead is stopping. But how do we know whether a car model so equipped would be sufficiently valued by consumers or would be taken as a joke of a car?

One promising possibility of resolving the above complications could be a careful empirical analysis of an industry when intraconnectivity is provided only sometimes; one could test whether there is a link between the times when connectivity is offered and the conditions under which the model predicts it should be offered. An example of such an industry is MP3 players (for transferring non-copyright-protected content), game consoles, or electronic readers (perhaps in a few years). For example, as of 2008, Zune was the only MP3 player able to share music files wirelessly with other Zune players. Because most markets are not fully covered, an empirical application would likely use the model without the fully covered market presented and analyzed in §4. That model predicts that any combination of firm's intraconnectivity choices is possibly optimal, and the pattern of intraconnectivity provision in an industry depends on how many new sales are due to customers who would otherwise stay out of the market and how many are due to customers who would otherwise buy the competing product. Thus, an empirical test of the model predictions would require estimation of the relative importance of category expansion and brand switching for the firms. Some additional challenges could be technological feasibility and costs. However, as we discussed in §5, as long as the total consumer benefits from connectivity (ignoring price changes) are greater than the total costs, the results are not overly sensitive to the fixed and variable production costs. It is therefore possible to test the model predictions with the demand and connectivity provision data alone. Doing so could require time-series data where the category elasticity to price varies across periods.

Electronic Companion

An electronic companion to this paper is available as part of the online version at http://dx.doi.org/10.1287/mksc.1120.0705.

Appendix A. Global Optimality of the First-Order Conditions of the Intraconnectivity Game (Fully Covered Market)

The second derivative of the profit functions with respect to own price are

$$\frac{\partial^2\Pi_1}{\partial p_1^2} = \frac{\partial^2\Pi_2}{\partial p_2^2} = -\frac{1}{t} \quad \text{in an } (N, N) \text{ subgame,}$$

$$\frac{\partial^2\Pi_1}{\partial p_1^2} = -\frac{2}{2t-\theta_C} \quad \text{and} \quad \frac{\partial^2\Pi_2}{\partial p_2^2} = -\frac{2}{2t-\theta_C} \quad \text{in a } (C, N) \text{ subgame, and}$$

$$\frac{\partial^2\Pi_1}{\partial p_1^2} = \frac{\partial^2\Pi_2}{\partial p_2^2} = -\frac{1}{t-\theta_C} \text{ in a } (C, C) \text{ subgame.}$$

Because all are always negative given the assumptions on the parameters, the first-order conditions solve for global profit maximum given the demand equations. Note that when a boundary condition is reached in the demand equations, the profit is either negative or smaller than the profit equations suggest. Therefore, if first-order conditions do not result in the boundary solution, equilibrium cannot be on the boundary. However, as noted above, for the demand to be uniquely determined in the (consumer choice subgame) equilibrium and given by Equations (7) and (8), we need to have $\theta_C < t$ in the (C, C) subgame and $\theta_C < 2t$ in the (C, N) subgame.

Appendix B. Global Optimality of the First-Order Conditions of the Interconnectivity Game (Fully Covered Market)

We will immediately provide the model solution with the possibly positive per-connection costs (note that substituting $c_C = c_I = 0$ leads to the solution of the main model). The first-order conditions have the unique solution $f_1^* = f_2^* = t + c_C + \theta_I - \theta_C$, corresponding to the profits $\Pi_1^* = \Pi_2^* = (t + \theta_I - \theta_C)/2 + (c_C - c_I)/4$. The second derivative of Firm 1's profit with respect to its price is $\partial^2\Pi_1/\partial f_1^2 = -(2(t+\theta_I-\theta_C) + c_C - c_I)/(2(t+\theta_I-\theta_C)^2)$. Hence, the first-order conditions define maximum if and only if $c_I < 2(t+\theta_I-\theta_C)+c_C$, which we have assumed. Note that this is also the condition under which the profit expressions above are positive.

Consider now what happens when the above condition on c_I is not satisfied. In this case, first-order conditions do not define optimal strategy by a firm. Because the profit functions are continuously differentiable everywhere, this means that the equilibrium must be on the boundary: $M=0$ or $M=1$. Assume $M=1$ and consider Firm 2's decision. When the market share of Firm 2 is small, Firm 2 has the per-customer cost c_I while Firm 1 has per-customer cost c_C. Therefore, Firm 1's price should be such that Firm 2 cannot achieve positive sales unless it lowers its price below its cost c_I. Indifference of the consumer located next to Firm 2 implies $V-t+\theta_C-f_1=V-c_I$; i.e., $f_1=c_I-t+\theta_C$. This price together with $f_2=c_I$ defines equilibrium with $M=1$. In equilibrium, $\Pi_1^*=c_I-t+\theta_C-c_C$, and $\Pi_2^*=0$.

Appendix C. Intraconnectivity Game Solution with Positive Per-Connection Costs

The solution follows the zero-cost derivations with the following changes. Given the costs in the profit function (the demand-conditional-on-prices derivation is exactly the same), the first-order conditions are as follows:

In an (N,N) subgame,

$$\frac{\partial\Pi_1}{\partial f_1}=\frac{t+f_2-2f_1}{2t}=0 \quad\text{and}\quad \frac{\partial\Pi_2}{\partial f_2}=\frac{t+f_1-2f_2}{2t}=0;$$

in a (C,N) subgame,

$$\frac{\partial\Pi_1}{\partial f_1}=\frac{t+f_2-2f_1}{2t-\theta_C}+\frac{2c}{2t-\theta_C}\cdot\frac{t+f_2-f_1}{2t-\theta_C}=0 \quad\text{and}$$
$$\frac{\partial\Pi_2}{\partial f_2}=\frac{t+f_1-2f_2}{2t}=0;\quad\text{and}$$

in a (C,C) subgame,

$$\frac{\partial\Pi_1}{\partial f_1}=\frac{t-\theta_C+f_2-2f_1}{2(t-\theta_C)}+\frac{c}{2(t-\theta_C)}\cdot\frac{t-\theta_C+f_2-f_1}{t-\theta_C}=0$$
$$\text{and}\quad \frac{\partial\Pi_2}{\partial f_2}=\frac{t-\theta_C+f_1-2f_2}{2(t-\theta_C)}+\frac{c}{2(t-\theta_C)}\cdot\frac{t-\theta_C+f_1-f_2}{t-\theta_C}=0.$$

Solving these, we obtain the following equilibrium prices, sales, and profits:

In an (N,N) subgame,

$$f_1^*=f_2^*=t\ \text{(prices)},\quad M_1^*=M_2^*=\frac{1}{2}\ \text{(sales)},\quad\text{and}$$
$$\Pi_1^*=\Pi_2^*=\frac{t}{2}\ \text{(profits)}.$$

In a (C,N) subgame,

$$f_1^*=(3t-\theta_C)(2t-\theta_C+2c_C)/A\quad\text{and}$$
$$f_2^*=(2t-\theta_C)(3t-2\theta_C+2c_C)/A\ \text{(prices)},$$
$$M_1^*=(3t-\theta_C)/A\quad\text{and}\quad M_2^*=(3t+2c_C-2\theta_C)/A\ \text{(sales)},$$
$$\Pi_1^*=(3t-\theta_C)^2(2t-\theta_C+c_C)/A^2\quad\text{and}$$
$$\Pi_2^*=(3t-2\theta_C+2c_C)^2(2t-\theta_C)/A^2\ \text{(profits)},$$

where $A=6t-3\theta_C+2c_C$. In (C,C) subgame,

$$f_1^*=f_2^*=t-\theta_C+c_C\ \text{(prices)},\quad M_1^*=M_2^*=\frac{1}{2}\ \text{(sales)},$$
$$\Pi_1^*=\Pi_2^*=\frac{2t-2\theta_C+c_C}{4}\ \text{(profits)}.$$

The proof that the prices are globally optimal is also similar with the correction that the second derivatives become

$$\frac{\partial^2\Pi_1}{\partial p_1^2}=-2\frac{2t-\theta_C+c}{(2t-\theta_C)^2}\quad\text{and}$$
$$\frac{\partial^2\Pi_2}{\partial p_2^2}=-\frac{2}{2t-\theta_C}\quad\text{in a } (C,N) \text{ subgame}\quad\text{and}$$
$$\frac{\partial^2\Pi_1}{\partial p_1^2}=\frac{\partial^2\Pi_2}{\partial p_2^2}=-\frac{2t-2\theta_C+c}{2(t-\theta_C)^2}\quad\text{in a } (C,C) \text{ subgame.}$$

Proof of Proposition 2. Comparing the profits when interconnectivity is offered and not, one immediately obtains that the profits are higher when interconnectivity is offered. This implies that it is optimal for each firm to agree to interconnectivity. In a noncooperative game where each firm makes a decision of whether to allow interconnectivity and only if both allow does interconnectivity materialize, (C,C)—not allowing interconnectivity by both firms—is also an equilibrium. But because offering interconnectivity is a weakly dominant strategy, we make the prediction that (IC, IC) will be the outcome.

Proof of Proposition 4. The following lemma is instrumental for the proof of this proposition.

Lemma 1. *Conditional on Firm 2 not offering intraconnectivity, Firm 1 offering intraconnectivity always decreases its profits, but it decreases profits of Firm 2 if and only if*

$$c_C<c_1(\theta_C,t)\equiv\frac{(3t-\theta_C)\sqrt{2(2t-\theta_C)}-(2t-\theta_C)(3t-4\theta_C)}{2(3t-2\theta_C)}.$$

Conditional on Firm 2 offering intraconnectivity, Firm 1 offering intraconnectivity decreases its profits if and only if $c_C<c_C^*(\theta_C,t)$ and decreases profits of Firm 2 if and only if $c_C<c_2(\theta_C,t)$, where c_2 is the positive root of

$$4c_2^3+4(8t-5\theta_C)c_2^2+(48t^2-84t\theta_C+29\theta_C^2)c_2$$
$$-2\theta_C(2t-\theta_C)(15t-7\theta_C).$$

Profits are higher in (N,N) than in (C,C) if and only if $\theta_C<2c_C$. Furthermore, we have

$$\theta_C<c_2(\theta_C,t)<c_1(\theta_C,t)<2\theta_C<c_C^*(\theta_C,t).$$

Proof of the Lemma. Assume that Firm 2 does not offer intraconnectivity. Then, if Firm 1 offers intraconnectivity, it will increase its profits by $(-(3t+2c-2\theta_C)(2ct+\theta_C(2t-\theta_C)))/(2(6t+2c-3\theta_C)^2)$, which is always negative given our assumptions. This proves the first claim. Firm 1 offering intraconnectivity increases Firm 2's profits by

$$\frac{(12t-8\theta_C)c^2+4(3t-4\theta_C)(2t-\theta_C)c-\theta_C(15t-8\theta_C)(2t-\theta_C)}{2(6t+2c-3\theta_C)^2},$$

which is negative if and only if c is between the two roots of the numerator. Given our assumptions, the smaller root turns out to be negative. Hence we obtain the second claim.

Similarly, when Firm 2 does offer intraconnectivity, the condition under which Firm 1 offering intraconnectivity increases profits of Firm 1 is that c has to be greater than $c_C^*(\theta_C,t)$, defined in the statement of Proposition 1 (that polynomial has either no other roots or the other roots are negative). This critical value increases in θ_C and is equal to

$t\sqrt{3}$ when $\theta_C = 0$. Firm 1 offering intraconnectivity helps Firm 2 when Equation (9) is positive.

The condition under which (C, C) results in higher profits than (N, N) is straightforward to check. To show the claimed order of the critical values, note that if we reparameterize θ_C as $\tau \cdot t$, we can express all expressions as a product of t and functions depending on τ only. It is then straightforward to check that their graphs do not intersect for $\tau \in [0, 1]$, which is our assumption. This concludes the proof of the lemma.

Now, to prove Proposition 4, observe that the equilibrium and the dominant strategy claims in Proposition 4 are straightforward to check given the profit comparisons and the ordering of the critical values of the cost stated in the lemma. To see that (C, C) Pareto dominates (N, N) whenever (C, C) is an equilibrium, we need to show that $c > c_C^*(\theta_C, t)$ implies $\theta_C < 2c$. The latter is equivalent to $c > \theta_C/2$. According to the lemma, we have $c_C^*(\theta_C, t) > 2\theta_C > \theta_C 2$, and the proof of Proposition 4 is complete.

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