

The strategic use of tying to preserve and create market power in evolving industries

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This article investigates how the tying of complementary products can be used to preserve and create monopoly positions. We first show how a monopolist of a product in the current period can use tying to preserve its monopoly in the future. We then show how a monopolist in one market can employ tying to extend its monopoly into a newly emerging market. Our analysis explains how a dominant firm can use tying to remain dominant in an industry undergoing rapid technological change. The analysis focuses on entry costs and network externalities. We also relate our analysis to the Microsoft case.

1. Introduction

■ Tying is a common practice in many markets, i.e., the seller of product A refuses to sell A to a consumer unless the consumer also purchases B (in this scenario product A is referred to as the tying product and B as the tied product). Examples are numerous, such as IBM's famous practice of requiring purchasers of its tabulating machines to also purchase tabulating cards from IBM, and Microsoft's more recent attempts to bundle Internet Explorer with Windows. Due to the ongoing battles between Microsoft and the U.S. Department of Justice concerning Microsoft's practices, the motivations and rationales behind tying arrangements have become the subject of both public policy and academic debates. We use dynamic models to reach two major findings. First, we show how a firm that is currently a monopolist in its primary market can use tying of a complementary product to preserve its monopoly position by deterring future entry into the primary market. Second, we show how tying can be used to transfer monopoly power from the primary market to a newly emerging market. We call these dynamic motives for tying "strategic tying of complementary products." The second result explains how a dominant firm can remain dominant in the presence of rapid technological change.¹

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Most previous analyses of tying have not focused on the ability of tying to enhance a monopolist's market power in its primary market, but instead have focused on either the ability of tying to achieve price discrimination or its ability to foreclose competition in the tied market.² A classic analysis in the price discrimination vein is that of metered sales. In this argument, consumers vary in terms of the quantity of the tied good demanded, where high-valuation consumers are assumed to have a high demand for the tied good while low-valuation consumers have a low demand. The argument is that by tying and charging a high price for the tied good, the monopolist is able to extract more of the surplus from the high-valuation/high-demand consumers. This is the standard interpretation for why IBM required consumers of its machines to also purchase cards from IBM.

The foreclosure argument is quite different. One variant of this argument is that the monopolist of one product increases its profits by earning monopoly profits in the now monopolized tied market. This argument was for a long time quite controversial because many believed that the monopolist need not monopolize the tied market to earn all the potential monopoly profits (see, e.g., Director and Levi (1956), Bowman (1957), Posner (1976), and Bork (1978)). In an important article, however, Whinston (1990) has shown that criticisms of the foreclosure argument depend on the tied market being characterized by perfect competition and constant returns to scale and that, given economies of scale and imperfect competition, tying can increase monopoly profitability.

In most of Whinston's analyses, tying is used to induce exit in the tied market, and the subsequent lack of substitute producers in the tied market enables the firm to increase its current profits in that market. For example, suppose that a restaurant in the only hotel on a resort island competes with local restaurants. If the hotel requires its guests to eat their meals at the hotel restaurant, then there may be fewer local restaurants as a consequence of the reduced patronage. Local residents will then have fewer alternatives, with the result that more of them may decide to frequent the hotel restaurant. In this case, tying can be profitable because it reduces competition in the tied market (we thank R. Gertner for this example).

In this article we build on and extend Whinston's important work.³ Our analysis is related to Whinston's in that we also focus on tying and foreclosure. However, we do not concentrate on the monopolist's ability to use tying and foreclosure to increase current profitability in the tied market. Rather, we use dynamic models to concentrate on the monopolist's ability to use tying and foreclosure to increase future profits by deterring entry of efficient firms into the monopolist's primary market and newly emerging markets. It is the strategic use of tying to deter the entry of efficient firms that raises the most interesting and difficult public policy issues.⁴

Our first major finding is that tying can be used to preserve a monopoly position in the tying (primary) market. We begin with a two-period setting in which a firm operates in both its primary market and a market for a complementary good. In the first period the firm is a monopolist in the primary market, say due to patenting, but in the second period there is the potential for entry at some cost by an alternative producer. The complementary good can also be produced by both the monopolist and the alternative producer, where the alternative producer can enter the complementary market at some cost in either the first or second period. We assume that the two firms have equivalent primary products in the second period but the alternative producer has a superior complementary product in both periods. In our specification the monopolist has no incentive to tie if there is no threat of entry into the primary market in the second period, but does have such an incentive when such entry is possible. There are two steps to the argument.

² Other justifications for tying include increasing efficiency in the presence of variable proportions, avoiding price regulations, giving secret price discounts, and quality assurance. See Davis, MacCriskin, and Murphy (1998) and Carlton and Perloff (2000) for discussions of efficiency rationales.

³ Other analyses related to Whinston's include Ordovery, Sykes, and Willig (1985) and Choi (1996). But neither of these articles considers the ability of tying to preserve a monopoly position in the tying market or extend it to a newly emerging market, which are the main focuses here.

⁴ Whinston does consider one setting in which tying is used to increase the firm's profits in the initially monopolized (i.e., the tying) market. In this analysis, tying and inducing exit in the tied market are used to eliminate a competitively supplied inferior product as a substitute. In contrast, our focus is on tying used to deter the entry of superior products.

First, tying can stop the alternative producer from ever entering the complementary market by eliminating the profits associated with the alternative producer selling complementary units in the first period, thereby making it impossible to cover the fixed costs of entry. Second, since in our model the return to the alternative producer of entering the primary market is capturing more of the surplus associated with its superior complementary product, when tying stops the alternative producer from entering the complementary market, it also stops the rival from entering the primary market.

One interesting aspect of our first analysis is that it suggests that the use of tying to preserve a monopoly position will be most important in industries characterized by substantial innovation where product lifetimes are short. As just discussed, an important part of our first analysis is that tying stops the alternative producer from earning profits from sales of complementary units before primary-market entry is possible, and this serves to lower the alternative producer's return to ever entering the complementary market. Given this, suppose that product lifetimes are very long while imitation lags are short, so the alternative producer can enter the primary market soon after the monopolist initially sells his primary product and can then sell his primary product plus his superior complementary product for a long time. In that case, tying has little ability to reduce the alternative producer's return to entering the complementary market, with the result that tying in order to deter entry of efficient rivals into the primary and complementary markets is rarely observed in equilibrium.

We also analyze whether our first finding regarding the monopoly-preservation role for tying holds in a setting characterized by only network externalities. In our analysis it is the complementary product that is characterized by network externalities, i.e., a consumer's gross benefit from the use of a firm's complementary product is positively related to the number of other consumers who use the same product. An example of a complementary product with network externalities is an applications program, such as Microsoft Word (a word processing program), where files can be traded among users. Our main result is that network externalities serve a role similar to a complementary-market entry cost, so that our first finding holds when the alternative producer faces no entry costs for the complementary good but the demand side of the market is characterized by network externalities. At the end of the analysis we relate this result to arguments put forth in the recent Justice Department case against Microsoft, in which Windows and a rival's Internet browser are complementary today, but in the future the browser could evolve into a substitute for Windows.

In addition to Whinston (1990), our first finding is related to earlier articles that consider disadvantages associated with an entrant having to simultaneously enter two markets rather than one. For example, Williamson (1979) argues that tying can reduce the probability of entry if the potential entrant only has experience relevant for producing one of the goods. His logic is that if the potential entrant lacks experience in one of the products, then tying can inhibit entry because it forces the firm to enter both markets, which, given its inexperience in one of the markets, results in a higher cost of capital. More recently, Choi and Stefanadis (2001) show a role for tying in a setting in which there is a single potential entrant for each of multiple complementary goods. They show that tying reduces the incentive for innovation for each entrant because successful innovation in a market is useful only when there is successful innovation in all markets. The result is that tying serves to preserve monopoly by reducing the probability that there will be successful innovation in all of the markets.

Our second major finding is that tying can allow a monopolist to acquire a monopoly position in a newly emerging market by "swinging" or transferring its initial monopoly to the newly emerging market. We regard this finding as answering the question, how can a dominant firm use strategic tying to remain dominant in industries undergoing rapid technological change? We use each of the models described above to prove our second finding. We first consider a variant of the entry-cost model. In this extension the newly emerging market is associated with the same complementary product as the primary market. In that case, because of the entry cost associated with the complementary product, tying primary and complementary goods lowers the profitability of a rival entering the newly emerging market in much the same way it lowered the profitability of

a rival entering the primary market in the above discussion. The conclusion is that tying primary and complementary goods can enable the initial monopolist to monopolize the newly emerging market by lowering the other producer's return to entering that market.

The second model that illustrates our second finding is a variant of the network-externalities model described above. Here we assume that in the first period there is a primary market that is monopolized and a complementary market characterized by network externalities, while in the second period a newly-emerging-market product becomes available that serves as a superior substitute for a system composed of primary and complementary goods. The two periods are linked because of positive network externalities across the products, i.e., a consumer's gross benefit from a producer's new product in the second period is positively related to the number of consumers of the firm's complementary product in the first and vice versa. We show that by tying its primary and complementary products, the initial monopolist can establish a monopoly position in the newly emerging market in the second period and thus retain its monopoly profits even after its primary product becomes obsolete.

Although much of the literature on this topic does not distinguish between the manner in which a firm ties its products, there are in fact two distinctly different ways in which tying is achieved in real-world settings. Some ties are achieved through contracting, while others are achieved through product design. For example, in the original 1936 IBM case, purchasers of IBM's tabulating machines were required to also purchase their tabulating cards from IBM—a tie achieved through contracting. In contrast, in the later 1970s case, there was an allegation that IBM's new central processing unit was interface incompatible with the plug-in components of rivals—a tie achieved through product design. Throughout the article we discuss the extent to which our various theoretical models apply to each of these two types of tying arrangements.

In addition to ties achieved through contracting and product design, we also consider the possibility that a monopolist can achieve a virtual tie through pricing. For example, suppose the primary and complementary products are used in fixed proportions. Then a monopolist of the primary product can achieve a virtual tie by setting a high price on the primary product and a very low price (say zero) on the complementary product. This achieves a virtual tie, since alternative producers of the complementary product cannot operate profitably given the very low price charged for this product by the monopolist. We discuss the situations in which a monopolist may employ virtual as opposed to real ties, and we prove the surprising result that a virtual tie may be used in settings characterized by network externalities but not in settings characterized by entry costs for the complementary good.

Much of the attention paid to tying arrangements stems from IBM's dominance of the computer industry in the 1960s and 1970s and Microsoft's dominance of the software market in the 1980s and 1990s, and each firm's use of tying arrangements in marketing its products. Our results are that in markets characterized by numerous complementary linkages, tying arrangements can be used not just to extend market power into tied markets, but also to preserve and create market power in the tying market and newly emerging markets. Thus, for example, it is possible that IBM's alleged tying of its mainframes and peripherals did not represent an ultimate goal of gaining market power in the peripherals markets, but rather tying was one of the tools the firm employed to retain market dominance in the mainframe market for so many years. Our results are particularly applicable to the IBM and Microsoft matters, because it was not IBM's market power in the peripherals markets or Microsoft's market power in the applications markets that created the bulk of public policy controversy; rather, most of the controversy stemmed from each firm's dominance of its primary market for such an extended period. Although our models explain the incentive and ability of dominant firms to use tying to preserve and extend market power, we caution that the policy implications for antitrust are complicated and refer the reader to Carlton and Waldman (1998) and Carlton (2001a, 2001b) for discussions of those issues.

2. Preserving monopoly through strategic tying given complementary market entry costs

■ In this section we show how a monopolist can strategically use the tying of complementary products to preserve an initial monopoly position in the presence of entry costs for the complementary good. In the next section we show how similar results can be derived in a setting characterized by network externalities rather than entry costs for the complementary good.

□ **The model.** We consider a two-period setting in which the monopolist is the sole producer in the primary market in period 1, say due to patenting, while there is the potential for entry into the primary market in period 2 by a single alternative producer. The monopolist and the primary market's alternative producer have the same constant marginal cost for producing the primary good, denoted c_p . There is a complementary good that can be produced by the monopolist and a single other firm, where the monopolist and the complementary market's alternative producer have the same constant marginal cost for producing the complementary good, denoted c_c . However, as described in more detail below, the alternative producer's complementary product is of higher quality than the monopolist's complementary product.⁵ Also, as described in more detail below, there is a sunk cost associated with entry into each market, and firms engage in Bertrand competition when more than one firm is active.

We assume that the primary market's single alternative producer and the complementary market's single alternative producer are the same firm. Without this assumption, an entrant into the primary market would lose money under the model's assumptions of constant marginal costs in the primary market, positive entry costs, identical primary products, and Bertrand competition. Alternatively, we could assume two different potential entrants and allow for payments between the firms. Our choice is to assume a single potential entrant that can produce both products, since this avoids the need to describe the bargaining process that would determine the size of such payments. The results that follow would be qualitatively unchanged if we assumed two different potential entrants each having the ability to produce only one product and Coasian-type bargaining.

The alternative producer has an entry or R&D cost associated with producing the first unit of the primary product, denoted E_{ap} , while its entry cost for producing the first unit of the complementary product is E_{ac} . The monopolist has entry costs for the primary and complementary markets, although we assume these costs are small enough that the monopolist always enters both markets in the first period. This allows us to focus on the entry decisions of the alternative producer. We denote the sum of the monopolist's entry costs as E_m . Note that for both the primary and complementary markets we could include both fixed costs and entry costs, but this would not change the qualitative nature of the results.

Consumers receive a positive benefit from consuming a system where a system consists of one primary unit and one complementary unit, while no benefit is received from consuming either a primary unit by itself or a complementary unit by itself.⁶ Consumers are indifferent between a unit of the primary good produced by the monopolist and a unit produced by the alternative producer, but they prefer the alternative producer's version of the complementary good (if consumers exhibited indifference among producers concerning both the primary and complementary products, there would never be entry in this model). Although this is the only case we consider in our formal analyses in this section, the results easily extend to the case where consumers prefer both the alternative producer's complementary good and its primary good. We discuss this alternative specification at the end of the next subsection.

⁵ The qualitative nature of the results would be unchanged if we assumed that consumers were indifferent between the monopolist's and the alternative producer's versions of the complementary good, but the alternative producer had a lower marginal cost of production for the complementary good. The same is true if scope economies over time, rather than entry costs, characterize production of the complementary good.

⁶ All the major results extend to the case in which consumers derive a positive benefit from a primary unit by itself, as long as the incremental benefit from consuming a complementary unit in addition to a primary unit exceeds the incremental cost. See Carlton and Waldman (1998).

To be precise, a consumer derives a gross benefit from a system in which the complementary good is produced by the monopolist equal to V , while his gross benefit from a system in which the complementary good is produced by the alternative producer is $V + \Delta$. We assume there are two cohorts of identical consumers, where there are N_1 consumers in cohort 1 and N_2 consumers in cohort 2. Consumers in cohort 1 are in the market in period 1, while consumers in cohort 2 are in the market in period 2 (to simplify the analysis, consumers in cohort 1 are assumed not to be in the market in period 2 even if they do not purchase anything in period 1). Further, there is a discount factor δ for both firms, $0 < \delta < 1$, where $\delta N_2(V - c_p - c_c) > N_1 \Delta / 2$. As we will show, this restriction ensures that the primary market monopoly is more valuable to the monopolist than the potential benefits associated with having the alternative producer offer its higher-quality complementary product.⁷

In the beginning of the first period, the monopolist decides whether to offer a tied product consisting of one unit of its primary and complementary goods or whether to offer the products individually.⁸ We assume this decision is binding for both periods 1 and 2, but the results would be very similar if we instead assumed that the monopolist's product choices for period 2 were decided at the beginning of period 2 (see footnote 12 for a discussion). Following Whinston (1990), we also assume that if the two goods are tied, a consumer cannot undo the tie. That is, if a consumer purchases a tied good consisting of one unit of the monopolist's primary good and one unit of its complementary good, then the consumer cannot add a unit of the alternative producer's complementary good to the system. This means that if the monopolist offers only a tied product, then in the first period the alternative producer will not be able to sell any units of the complementary good. In contrast, in the second period the alternative producer would not be locked out of the market because it can produce both products.

From a real-world perspective, when a firm commits to bundle its products, the resulting system can either be incompatible with the alternative producer's complementary good or compatible with the alternative producer's complementary good. The former case is what we mean when we say that consumers cannot undo ties, while we refer to the latter case as consumers being able to undo ties. Note that when consumers can undo ties, the act of tying is similar to setting the price of the complementary good to zero. In contrast, when consumers cannot undo ties, there is the added constraint that the alternative producer cannot sell complementary units in the first period even if the incremental benefits associated with the alternative producer's superior complementary product exceeds the marginal cost of production (this is also true in the second period if the alternative producer does not enter the primary market).⁹

In the first period, if the monopolist decides to offer its primary and complementary goods as individual products, then the alternative producer must decide whether or not to enter the complementary market. If the alternative producer enters, then prices are determined by Bertrand competition. In the second period, the alternative producer decides whether or not to enter the primary market and, if it did not enter the complementary market previously, whether or not to enter the complementary market. Since in this model there is no incentive for the alternative producer to tie, to simplify the exposition we assume that when the alternative producer is in both markets in the second period, it offers individual products. As in the first period, if both firms are active in the second period, then prices are determined by Bertrand competition. Finally, we restrict attention to pure-strategy subgame-perfect Nash equilibria.

⁷ We also assume that N_1 is sufficiently large so that if the alternative producer can never enter the primary market but chooses to enter the complementary market, it enters the complementary market in the first period. The restriction that ensures this is that $N_1 > (1 - \delta)N_2$. Note that as discounting becomes small, i.e., δ approaches one, this restriction reduces to $N_1 > 0$.

⁸ There is no reason for a firm to offer both tied and individual products in this model, because consumers are identical rather than heterogeneous. See Adams and Yellen (1976) for an analysis in which consumers are heterogeneous and firms sometimes offer both tied and individual products to more effectively price discriminate.

⁹ If consumers could undo ties, then the results are unchanged if $c_c \geq \Delta$, while there are fewer parameterizations characterized by tying if $c_c < \Delta$. Note that when $c_c < \Delta$, tying does not stop the alternative producer from selling complementary units in period 1, but because it can reduce the alternative producer's profit from doing so, it is still sometimes used by the monopolist as a way of deterring entry.

One interpretation of our assumption that in the first period the alternative producer decides to enter the complementary market after the monopolist's tying decision is that our first analysis concerns ties achieved through product design. Think of the alternative producer's complementary market entry cost as that part of the product design or R&D cost that can only be incurred after the alternative producer observes the design of the monopolist's primary product, and assume that tying means the monopolist designs its primary and complementary products so that they are a single physical unit.¹⁰ Since the alternative producer decides whether to incur the complementary market entry cost only after it sees the design of the monopolist's primary product, we have that the entry decision occurs after the monopolist's tying decision. As discussed in more detail later, the analysis in the next section applies equally well to ties achieved through product design as to ties achieved through contracting.

In this model, Bertrand competition sometimes does not result in a unique set of prices. To see this, suppose the monopolist produces independent products and the alternative producer has entered the complementary market in period 1. One equilibrium set of prices in period 1 is that the monopolist charges $V - c_c$ for its primary product and the alternative producer charges $\Delta + c_c$ for its complementary product (here and in the following set of equilibrium prices, consumers purchase the complementary good from the alternative producer as long as the monopolist charges more than c_c for its complementary product). In this equilibrium, the alternative producer receives all the surplus associated with consumers preferring its version of the complementary product. However, in another set of equilibrium prices, the monopolist charges $V + \Delta - c_c$ for its primary product and the alternative producer charges c_c for its complementary product. In this equilibrium the monopolist receives all the surplus associated with consumers preferring the alternative producer's version of the complementary good. In fact, any division across the two sellers is consistent with equilibrium.

In our analysis we assume that if the alternative producer has only entered the complementary market, then the prices that emerge divide evenly across the two sellers the surplus associated with consumers preferring the alternative producer's version of the complementary good (one interpretation of our assumption that the surplus is divided equally between the firms is that prices are determined by the Nash bargaining solution—see Nash (1950)). The same qualitative results would follow from any division that gave each firm a strictly positive proportion of the surplus, but the results would not follow if the surplus was either all received by the monopolist or all received by the alternative producer. In the former case, tying would not decrease the alternative producer's return to entering the complementary market in the first period (since the alternative producer would earn zero rents from such entry whether or not the monopolist ties), and as a result tying would not affect the alternative producer's primary-market entry decision in the second period. In the latter case, if the monopolist offered individual products and the alternative producer were to enter the primary market in the second period after entering the complementary market in the first, there would be no increase in the proportion of the surplus received by the alternative producer. The result is that even if the monopolist did not tie, the alternative producer would never enter the primary market.

□ **Analysis.** As a result of our assumption that it faces low entry costs, the monopolist enters both markets in the first period. Our focus is on the entry decisions of the alternative producer, and the extent to which the monopolist tries to affect these decisions by offering a tied product. Our main result is that the monopolist will sometimes use tying to deter entry by the alternative producer into both the primary and complementary markets. This strategy increases the monopolist's profitability by preserving its monopoly in the primary market in the second period.

We begin with a benchmark analysis in which the alternative producer cannot enter the primary market in either period (a simple interpretation is that $E_{ap} = \infty$). In this benchmark

¹⁰ To be precise given this interpretation, our specification is equivalent to assuming that the part of the alternative producer's product design or R&D cost that can be incurred prior to the alternative producer observing the monopolist's primary product equals zero. Allowing this cost to be positive, however, would not qualitatively change the results.

analysis, however, there is still the possibility that the monopolist will use tying to deter entry into the complementary market, although we will show that the monopolist does not have an incentive to do so. Our argument in this benchmark case is closely related to Whinston's first analysis of tying and complementary goods. In that analysis, Whinston considers a setting in which, as in our model, all uses of the complementary good require the primary good, and he shows that the monopolist has no incentive to tie because the monopolist is actually helped when the alternative producer enters the complementary market. The proofs of this and all other results are in the Appendix.

Proposition 1. Suppose $E_{ap} = \infty$. Then there exists a value $E'_{ac}, E'_{ac} > 0$, such that every equilibrium is characterized by (i) and (ii) if $E_{ac} > E'_{ac}$, while (iii) and (iv) characterize equilibrium behavior if $E_{ac} < E'_{ac}$. Also, overall monopoly profitability is higher when $E_{ac} < E'_{ac}$.

- (i) The monopolist offers individual or tied products.
- (ii) The alternative producer never enters the complementary market.
- (iii) The monopolist offers individual products.
- (iv) The alternative producer enters the complementary market in the first period.

Proposition 1 tells us that in the absence of an entry threat into the primary market, the monopolist never ties in order to deter entry into the complementary market. That is, although offering a tied product is an optimal strategy for the monopolist when $E_{ac} > E'_{ac}$ (but not the only optimal strategy), this is not because the monopolist wants to deter entry. Rather, the cause and effect are in the other direction. Because the alternative producer's entry cost is sufficiently high that no entry will take place, there is no cost (and no return) to the monopolist from offering a tied product.

The logic for this finding is similar to Whinston's argument referred to above. Suppose for a moment that the alternative producer does not have the option of entering the complementary market. By setting the price for the complementary good at marginal cost and the price for the primary good at the optimal bundle price minus the complementary good price, the monopolist can sell individual products and earn the same profits as it can by tying. Given this, suppose the alternative producer has the option of entering the complementary market and the monopolist does not tie. Since the monopolist can guarantee itself the profits associated with tying by setting the prices for the primary and complementary goods as before, if in equilibrium the alternative producer sells its complementary good, this can only help monopoly profitability. Hence, in this case the monopolist has no incentive to tie.

We now consider what happens when the alternative producer has the option of entering the primary market in the second period. This case works quite differently from the benchmark case analyzed above. The reason is that, as opposed to what is true when the alternative producer enters only the complementary market, when it enters both the primary and complementary markets, overall monopoly profitability is hurt rather than helped. As a result, the monopolist sometimes deters entry into both markets by offering a tied product. We begin with a preliminary result concerning the alternative producer's incentive to enter the primary market in the second period. Below, π_{a2}^{pc} denotes the alternative producer's second-period profitability when the alternative producer enters the complementary market in period 1 and the primary market in period 2, and π_{a2}^c denotes the alternative producer's second-period profitability when the alternative producer enters the complementary market in period 1 and does not enter the primary market in period 2 (and the monopolist offers independent products).

Lemma 1. There exists a value $E_{ap}^* > 0$ such that $\pi_{a2}^{pc} > \pi_{a2}^c$ if $E_{ap} < E_{ap}^*$, while $\pi_{a2}^{pc} < \pi_{a2}^c$ if $E_{ap} > E_{ap}^*$.

Lemma 1 is straightforward. It says that if the monopolist offers individual products and the alternative producer enters the complementary market in the first period, then the alternative producer stays out of the primary market in the second period if the cost of entering that market is sufficiently high. But it enters if the cost is sufficiently low. The next step is to consider in

more detail what happens if the alternative producer has entered both markets by the beginning of the second period. Below, π_m denotes overall monopoly profitability, π_{mj} denotes monopoly profitability in period j , π_a denotes the overall profitability of the alternative producer, and π_{aj} denotes the alternative producer's profitability in period j .

Suppose the alternative producer has entered both markets by the beginning of the second period. Bertrand competition yields that purchasing a system from the monopolist will cost $c_p + c_c$, purchasing a system from the alternative producer will cost $c_p + c_c + \Delta$, and consumers purchase the complementary product from the alternative producer (sales of the primary product may be split across the two firms).¹¹ In turn, second-period monopoly profitability is given by $\pi_{m2} = 0$, while $\pi_{a2} = N_2\Delta - E_{ap}$ if the alternative producer had entered the complementary market in period 1 but $\pi_{a2} = N_2\Delta - E_{ap} - E_{ac}$ if it had not. There are two results of interest here. First, as opposed to what was true before, second-period monopoly profitability is now below rather than above second-period profitability in the absence of any entry. Second, the alternative producer's second-period profitability depends on whether it had entered the complementary market in the first period. If it had not, then the alternative producer bears that entry cost in the second period with a resulting decrease in second-period profitability.

The above analysis suggests that the monopolist sometimes has an incentive to deter entry into the complementary market in the first period, where this arises not from the effect on first-period profitability but rather because of the effect on second-period and overall profitability. That is, the benchmark analysis tells us that deterring entry into the complementary market in the first period reduces the monopolist's first-period profitability. However, this action reduces the alternative producer's return to operating in the primary and complementary markets in the second period, with the possible result that entry into both markets is deterred, in which case second-period and overall monopoly profitability increase. Proposition 2 shows that this argument sometimes results in the monopolist offering a tied product.

Proposition 2. Suppose $E_{ap} < E_{ap}^*$. Then there exist values E_{ac}^* and E_{ac}^{**} such that, if $E_{ac}^* < E_{ac} < E_{ac}^{**}$, then the unique equilibrium is characterized by (i) and (ii).

- (i) The monopolist offers a tied product.
- (ii) The alternative producer never enters either market.

Proposition 2 says that if the alternative producer would enter the primary market in the second period given that the monopolist offers individual products and the alternative producer had previously entered the complementary market ($E_{ap} < E_{ap}^*$), then the monopolist sometimes offers a tied product and in this way deters entry into both markets. In particular, the monopolist does this when the alternative producer's cost of entering the complementary market falls in an intermediate range (which may or may not exist, as discussed below). The logic is that if this entry cost is low ($E_{ac} < E_{ac}^*$), the monopolist has no incentive to tie because the alternative producer would respond by entering both markets in the second period, while if this cost is high ($E_{ac} > E_{ac}^{**}$), there is no incentive (or disincentive) for the monopolist to tie because the alternative producer would never enter either market even if the monopolist offered individual products. For intermediate values, however, the alternative producer will enter both markets if the monopolist offers individual products, but never enters either market if the monopolist ties.¹²

A related issue concerns the restriction imposed earlier that $\delta N_2(V - c_p - c_c) > N_1\Delta/2$. Starting from no entry in either market, the left side of this equation is the present discounted value of the loss in second-period monopoly profits if the alternative producer is in both markets in the second period, while the right side is the gain in first-period monopoly profits if the alternative

¹¹ If we allowed the alternative producer to tie, then by tying it could force all consumers to purchase primary units from itself. However, this would not increase the alternative producer's profitability.

¹² A natural question is, instead of the monopolist's first period tying decision being binding for both periods, what happens if product choices for period 2 are made at the beginning of period 2? The answer is, if $E_{ap} < E_{ap}^*$ and $E_{ac}^* < E_{ac} < E_{ac}^{**}$, then the monopolist deters entry into both markets by tying in period 1 and offering either tied or individual products in the second period.

producer enters the complementary market in the first period. Hence, for tying and no entry to be preferred by the monopolist over the alternative producer entering the complementary market in the first period and the primary market in the second, it must be the case that $\delta N_2(V - c_p - c_c) > N_1 \Delta/2$.

Our analysis here can be interpreted in terms of one of Whinston's arguments concerning tying. Whinston considers a setting in which an alternative producer of a complementary good faces a single cost for entry into two distinct markets—a systems market in which the monopolist's primary good is essential and a market for the complementary good by itself. In Whinston's analysis, the monopolist ties its primary and complementary goods, with the result that the alternative producer does not incur the entry cost and the monopolist increases its profits in the separate market for the complementary good. One can interpret our analysis along these lines. The first period is like Whinston's systems market in that the monopolist's primary good is essential, while the second period is like Whinston's complementary-good market in that the monopolist's primary good is not essential. One difference between the analyses is that in Whinston's analysis, the return to tying is determined by the profitability of monopolizing the complementary market, whereas here tying preserves monopoly of the primary good so that the return to tying is determined by the profitability of monopolizing the systems market.

One interesting question is, when the monopolist has an incentive to tie, what is the effect on social welfare from a prohibition on tying? The answer is that when the monopolist has an incentive to tie, a prohibition on tying increases social welfare. The logic here is as follows. Suppose the government imposes a ban on tying and, as a result, the alternative producer enters the complementary market in period 1 and the primary market in period 2. In period 2, the alternative producer earns Δ per consumer, which is exactly his social contribution in period 2; in period 1, he earns $\Delta/2$ per consumer, which is half his social contribution in period 1, while he incurs costs E_{ap} and E_{ac} . That is, because of a positive externality associated with entry into the complementary market in the first period, the alternative producer will only enter the two markets when the societal benefits exceed the cost. Hence, banning tying is socially optimal. Another interesting question is, why does the monopolist need to tie rather than simply price the complementary good at zero, since setting the complementary-good price at zero is in some respects the effect of a tie? (We call this a virtual tie.) The answer, as we discuss in more detail in the next section, is that setting the complementary-good price at zero in this analysis is not a credible strategy.

Another interesting question is, what would happen if consumers preferred both the alternative producer's complementary product and its primary product? The answer is that all the major results of the analysis would still hold.¹³ That is, since the alternative producer's second-period profit associated with being active in both markets in the second period would still be lower if it had not entered the complementary market in the first period, the monopolist, by tying and deterring entry into the complementary market in the first period, would still reduce the alternative producer's return to being active in both markets in the second period. The result is that the monopolist would sometimes use tying to deter efficient entry into both markets. Similarly, suppose consumers preferred both the alternative producer's complementary product and the monopolist's primary product. Then all the major results of the analysis would still hold as long as the consumers did not prefer the monopolist's primary product by too much.

Although we have not formally shown the result, we also believe that most of our main findings would hold even if we relaxed the assumptions that consumers are identical and that there is Bertrand competition. That is, suppose the setting was not characterized by these two assumptions, but the strategic interaction between the firms was such that the alternative producer sometimes had an incentive to enter both markets because it derived more of the surplus associated with its superior complementary product when it was in both markets rather than just the

¹³ We have also worked out an example in which tying stops consumers from combining the alternative producer's superior primary product with the monopolist's superior complementary product. In this example, because consumers have a lower value for the alternative producer's superior primary product when it cannot be combined with the monopolist's superior complementary product, tying again results in no entry.

complementary market. Since tying and deterring entry into the complementary market in the first period would still reduce the alternative producer's return to being active in both markets in the second period, the monopolist would still sometimes tie in order to deter entry into the two markets. On the other hand, the social welfare implications associated with banning tying in such a world seem less clear cut to us. Still, given that there is typically a higher social welfare return to having competition when consumers are heterogeneous rather than homogeneous, our finding of a social welfare increase associated with banning tying might also be robust to relaxing these assumptions.

As a final point, throughout we assume the monopolist and the alternative producer cannot sign a long-term contract at the beginning of the first period that commits the monopolist to offer a tied product containing the monopolist's primary good and the alternative producer's complementary good, and that specifies both the first-period and second-period prices the monopolist must pay for the alternative producer's product. If such a contract were feasible, then tying its own primary and complementary goods would never be equilibrium behavior for the monopolist. The reason is that both firms, by appropriately setting the prices in such a contract, can be made better off than having the monopolist tie its own primary and complementary goods, and the alternative producer's second-period profits can be made sufficiently high that it has no incentive to enter the primary market in the second period.

One reason such a contract might not be employed in a real-world setting is the possibility that the contract might be ruled illegal by the antitrust authorities as a way of achieving an illegal collusive outcome in which the monopolist pays the alternative producer not to enter the primary market. A second reason such a contract might not be employed concerns the issue of quality improvements. That is, in a world where quality improves from period to period, the monopolist would not want to enter into such a contract unless it also specified the second-period quality of the alternative producer's complementary product. In turn, to the extent that quality is not verifiable by the courts because of the difficulty of specifying exactly what "high quality" means, such a contract might not be an attractive way for the monopolist to stop the alternative producer from entering the primary market.

□ **When is tying important?** In this subsection we focus on the critical values E_{ap}^* , E_{ac}^* , and E_{ac}^{**} of Proposition 2 and in this way identify the circumstances in which tying to deter entry is likely to be more important.¹⁴ There are three conditions that must hold for there to be a unique tying equilibrium: (i) the alternative producer would enter the primary market in period 2 if it entered the complementary market in period 1; (ii) the alternative producer does not find it profitable to enter both markets in period 2; and (iii) if the monopolist does not tie, then the alternative producer finds it profitable to enter the complementary market in period 1 and the primary market in period 2. Condition (i) yields equation (1), condition (ii) yields equation (2), and condition (iii) yields equation (3).

$$\delta N_2(\Delta/2) - \delta E_{ap} > 0 \quad (1)$$

$$\delta N_2\Delta - \delta(E_{ap} + E_{ac}) < 0 \quad (2)$$

$$N_1(\Delta/2) + \delta N_2\Delta - E_{ac} - \delta E_{ap} > 0. \quad (3)$$

Equation (1) yields $E_{ap}^* = N_2\Delta/2$. Equation (2) yields $E_{ac}^* = N_2\Delta - E_{ap}$, where $E_{ac}^* > 0$ if $E_{ap} < E_{ap}^*$. Equation (3) yields $E_{ac}^{**} = N_1(\Delta/2) + \delta(N_2\Delta - E_{ap})$. Combining terms yields $E_{ac}^{**} - E_{ac}^* = N_1(\Delta/2) + (\delta - 1)(N_2\Delta - E_{ap})$.

Inspection of the last expression yields $E_{ac}^{**} - E_{ac}^* > 0$ for some parameterizations but not for all. For example, $E_{ac}^{**} - E_{ac}^* > 0$ when N_1 is large and/or δ is sufficiently close to one. The logic here is that tying will be effective in deterring entry when not being able to sell complementary

¹⁴ We would like to thank Joseph Harrington and Michael Whinston for suggesting to us the analysis of this subsection.

units in the first period significantly lowers the alternative producer's profitability of entering the primary and complementary markets. In turn, this will be the case when the number of consumers in the first period is large, i.e., N_1 is large, and when there is little return for the alternative producer in delaying the complementary market entry cost till the second period, i.e., δ is close to one.

One can use these expressions to think about how important the possibility of tying is, where we will say that tying is more important when $E_{ac}^{**} - E_{ac}^*$ is positive and large. In particular, think of our two-period model as a reduced-form version of a T -period model, where the alternative producer can enter the complementary market in period 1 and the primary market in period t' . In this interpretation, the first period captures periods 1 through $t' - 1$, while the second period captures t' through T . Call T the lifetime of the primary product and t' the primary product imitation lag.

Given this interpretation, our model suggests that tying will be more important when the lifetime of the primary product is short and the imitation lag is long. To see this, start from a parameterization in which $E_{ap} < E_{ap}^*$ and $E_{ac}^{**} > E_{ac}^*$, and suppose that we hold t' fixed but increase T . In our reduced-form model this is equivalent to increasing N_2 —the number of consumers in the market after the firm can enter the primary market. Given $\delta < 1$, an increase in N_2 causes $E_{ac}^{**} - E_{ac}^*$ to become smaller (if N_2 increases enough, $E_{ac}^{**} - E_{ac}^*$ would, in fact, become negative), i.e., the importance of tying is negatively related to the lifetime of the primary product. Now suppose that T is held fixed and t' is decreased—there is a shortening of the imitation lag. In our reduced-form model, this is equivalent to decreasing N_1 , increasing N_2 , and increasing δ . Here we find that the importance of tying is positively related to the imitation lag in that a large-enough decrease in t' will cause $E_{ac}^{**} - E_{ac}^*$ to decrease, since N_1 would eventually approach zero.¹⁵

In summary, this analysis suggests that tying will be most effective for preserving monopoly in industries in which product lifetimes are short but imitation lags are long (so that it takes a producer substantial time to copy a competitor's new-product introduction). Given this, it is high-technology industries such as computing where we think that our argument is most important. The reason is that such industries are often characterized by frequent new-product introductions that limit product lifetimes by making old products obsolete, while at the same time the complex nature of the products can result in substantial imitation lags.

3. Preserving monopoly through strategic tying when network externalities exist

■ The previous section demonstrated a monopoly preservation role for tying when the alternative producer faces entry costs for the complementary good. In this section we assume away entry costs for the complementary good and show that the presence of network externalities for the complementary good can similarly result in the strategic use of tying to deter entry into the primary market (see, e.g., Katz and Shapiro (1986, 1994) and Farrell and Saloner (1986, 1992) for articles that focus on network externalities). At the end of this section we relate this analysis to the facts in the Microsoft case.

□ **Model and analysis.** In addition to assuming no entry costs for the complementary good, we make the following changes to the model analyzed in Section 2. Let N_{mj} be the number of consumers in cohort j who own a system consisting of one unit of the primary good and one unit of the monopolist's complementary good, while N_{aj} is the number of consumers in cohort j who own a system consisting of one unit of the primary good and one unit of the alternative producer's complementary good. A consumer derives a gross benefit from a system in which the complementary good is produced by the monopolist equal to $V + v(N_{m1} + N_{m2})$, $v' > 0$, while

¹⁵ We have formally worked through a T -period version of our model and shown that these claims concerning T and t' are valid. One interesting aspect of that analysis is that tying never occurs when products are infinitely lived. We would like to thank Joseph Harrington for first pointing this out to us.

a consumer derives a gross benefit from a system in which the complementary good is produced by the alternative producer equal to $V + \Delta + v(N_{a1} + N_{a2})$. In this specification, $v(\cdot)$ embodies network externalities, i.e., the gross benefit a consumer derives from a system is positively related to the number of other consumers with a similar system.¹⁶ As mentioned earlier, one example of a complementary good with network externalities is an applications program, such as Word, where files can be traded among users. Also, to simplify the analysis we now assume $N_1 = N_2 = N$ and $\delta = 1$, i.e., cohorts are of equal size and there is no discounting.

In each of periods 1 and 2, because of network externalities, a given set of prices will frequently not result in a unique set of purchase decisions by the consumers. Similar to the approach taken in Katz and Shapiro (1986), we assume that purchase decisions are made as if consumers could coordinate behavior. That is, when there are multiple equilibria for a subgame that starts with consumer purchase decisions, we rule out the equilibria that are Pareto dominated for the consumers purchasing in that period. Another way to put this is that we restrict attention to perfectly coalition-proof Nash equilibria (see Bernheim, Peleg, and Whinston (1987) for a discussion of this refinement). Additionally, as in the previous section, in this model Bertrand competition will sometimes not result in a unique set of prices. If this occurs in period 2 we assume, as we did previously, that the prices that emerge split evenly across the two sellers the surplus associated with consumers preferring the alternative producer's version of the complementary good, although as before any split that gave each firm a strictly positive proportion of the surplus would yield the same qualitative results.¹⁷ Another change is that we now assume $V + v(N) - c_p - c_c > 2\Delta$ rather than the assumption of the previous section that $V - c_p - c_c > \Delta/2$ (this is the correct expression for the condition imposed previously given $N_1 = N_2 = N$ and $\delta = 1$).¹⁸

There are three points to note regarding the model. First, an important difference between this model and the previous one is that here the size of the second-period surplus associated with consumers preferring the alternative producer's complementary good depends on first-period consumption decisions. That is, due to network externalities, this surplus is larger if cohort 1 consumers purchased the alternative producer's complementary product and smaller if they purchased the monopolist's complementary product. Second, we continue to assume as before that in the first period the monopolist chooses whether to tie prior to prices being chosen. However, the results of the analysis would be unchanged if we instead assumed that in the first period the monopolist's product choices are made at the same time prices are chosen. This means that the analysis here applies equally well to ties achieved through product design, where it is most natural to assume that tying occurs prior to pricing, as to ties achieved through contracting, where it is most natural to assume that tying and pricing decisions are made simultaneously. Third, although the alternative producer does not face an entry cost for the complementary good in this model, the alternative producer does face an entry cost for the primary product. That is, the alternative producer cannot produce primary units in the first period, but by incurring a cost E_{ap} at the beginning of the second period, it can produce primary units at a constant marginal cost of c_p in the second period.

Before proceeding, one natural question is, what happens in this model if the alternative producer cannot enter the primary market in either period? In Section 2, if the alternative producer could never enter the primary market, then the monopolist did not have an incentive to tie. This

¹⁶ In this specification, each consumer derives equal benefit from consumers in the same cohort who purchase a similar system as from consumers in the other cohort, but allowing differential benefits would not change the qualitative results. Similarly, allowing each consumer to derive a small positive benefit from consumers who purchase a system with the "other" complementary good would also not affect the qualitative results.

¹⁷ Because the first-period consumption decisions affect the size of the surplus in the second period, the assumption that the surplus is divided equally across the two sellers has a well-defined meaning for the second period but not the first (in Section 2 the assumption was well defined for both periods). Given this, we impose the assumption only for the second period.

¹⁸ As discussed in footnote 17, here we impose no assumption concerning how the multiple equilibria problem is resolved when Bertrand competition does not result in a unique set of first-period prices. Because of this, $V + v(N) - c_p - c_c > 2\Delta$ is needed to ensure that the primary-market monopoly is more valuable to the monopolist than the potential benefits associated with the alternative producer's superior complementary product.

is not true for the current model because of the introduction of network externalities, where we note that this is the case even though the monopolist's primary product would be essential in both the first and second periods. In other words, if primary market entry by the alternative producer is never possible, then for certain parameterizations there exists an equilibrium in which the monopolist ties in order to deter entry into the complementary market. The logic here is that if the monopolist sold individual products and set the price for the complementary good at cost, then in contrast to what was true previously, monopoly profitability could actually be lower than when the monopolist ties. The reason is that if cohort 1 consumers purchase the alternative producer's complementary good, then, due to network externalities, the value to any particular consumer of a system composed of both of the monopolist's products would be lower than the corresponding value when the monopolist ties.

We first consider what happens if the alternative producer enters the primary market in period 2, where we initially focus on parameterizations characterized by $v(2N) - v(N) > \Delta$, since the argument is simpler for these parameterizations. There are two cases. The first case is that consumers purchased complementary units from the alternative producer in period 1. In this case, Bertrand competition yields that purchasing a system from the monopolist will cost $c_p + c_c$, purchasing a system from the alternative producer will cost $c_p + c_c + \Delta + v(2N) - v(N)$, and consumers purchase the complementary product from the alternative producer (sales of the primary product may be split across the firms—see footnote 11). In turn, second-period monopoly profitability is given by $\pi_{m2} = 0$, while $\pi_{a2} = N(\Delta + v(2N) - v(N)) - E_{ap}$. The second case is that consumers purchased complementary units from the monopolist in period 1. In this case, given $v(2N) - v(N) > \Delta$, Bertrand competition yields that purchasing a system from the monopolist costs $c_p + c_c + v(2N) - v(N) - \Delta$, purchasing a system from the alternative producer costs $c_p + c_c$, and consumers purchase the complementary product from the monopolist. In turn, $\pi_{m2} = N(v(2N) - v(N) - \Delta)$ and $\pi_{a2} = -E_{ap}$.

There are two results of interest in the above analysis. First, if cohort 1 consumers purchase complementary units from the alternative producer, then entry into the primary market in the second period hurts the monopolist's second-period and overall profitability. Second, if cohort 1 consumers purchase complementary units from the monopolist, then the alternative producer would not enter the primary market in the second period because such entry results in negative profits. Together, these two results suggest that the monopolist will sometimes deter entry into the primary market in period 2 by behaving in a manner that causes cohort 1 consumers to purchase complementary units from the monopolist. We formalize this argument in Proposition 3.

Proposition 3. If $v(2N) - v(N) > \Delta/2$, then there exist values E_{ap}^* and E_{ap}^{**} , $0 \leq E_{ap}^* < E_{ap}^{**}$, such that for all $E_{ap}^* < E_{ap} < E_{ap}^{**}$, every equilibrium is characterized by (i) and (ii).

- (i) There is no entry into the primary market in the second period, and consumers in both cohorts purchase both primary and complementary goods from the monopolist.
- (ii) The monopolist offers a tied product, or offers individual products but in the first period charges a "high" price for the primary product and a "low" price for the complementary product (see the proof for the exact definitions of "high" and "low").

Proposition 3 tells us that the monopolist will sometimes use either a real tie or a virtual tie achieved through pricing to both stop the alternative producer from selling complementary units and deter its entry into the primary market. The logic for the case $v(2N) - v(N) > \Delta$ was discussed above. When the monopolist sells its products in a manner that causes cohort 1 consumers to purchase complementary units from the monopolist, the alternative producer loses money in the second period if it enters the primary market. The result is that the alternative producer does not enter the primary market in the second period, and this in turn increases overall monopoly profitability. The restriction on E_{ap} captures that, for this logic to result in a reason for the monopolist to tie, E_{ap} must be sufficiently small that the alternative producer would enter the primary market if it sold complementary units to all cohort 1 consumers (if $v(2N) - v(N) > \Delta$, then $E_{ap}^* = 0$).

The logic for the case $\Delta/2 < v(2N) - v(N) \leq \Delta$ is similar. In this case, independent of

what happens in the first period, if the alternative producer enters the primary market in the second period, then it sells complementary units in the second period (if $v(2N) - v(N) = \Delta$, this is only one possible outcome if first-period consumers purchased complementary units from the monopolist). The surplus associated with the alternative producer's complementary units in the second period, however, will be lower if cohort 1 consumers purchased complementary units from the monopolist. This means that since the alternative producer's return to entering the primary market is positively related to the surplus associated with its complementary units, the alternative producer's return to entering the primary market is also lower if cohort 1 consumers purchased complementary units from the monopolist. The result is that, as in the other case, the monopolist, by selling its products in a manner that causes cohort 1 consumers to purchase its complementary units, can sometimes make primary-market entry unprofitable, which in turn increases overall monopoly profitability. Also similar to the other case, the restriction on E_{ap} captures that for this logic to result in a reason for for the monopolist to tie, E_{ap} must be in a range such that the alternative producer would enter the primary market in period 2 if the alternative producer sold complementary units to all cohort 1 consumers, but would not enter if the monopolist sold complementary units to all cohort 1 consumers.

An interesting aspect of Proposition 3 is that for some parameterizations the monopolist need not actually tie its products to achieve its goal, but can rather employ a virtual tie achieved through first-period prices. The logic is that if the monopolist's complementary good in the first period is priced sufficiently low, then the alternative producer cannot profitably sell complementary units. However, a virtual tie achieved through first-period pricing is not feasible for some parameterizations; one reason for this is that we do not allow the monopolist to charge a negative price for the complementary good (see the proof of Proposition 3 for details). Note that when the monopolist employs a real tie rather than a virtual tie because the complementary-good price cannot be negative, the monopolist must profit from keeping the alternative producer in the first period from selling complementary units even when the incremental benefits associated with the alternative producer's superior complementary product exceed the marginal cost of production. In contrast, if we had assumed that ties could be undone rather than that they cannot, then a real tie and a virtual tie achieved through first-period prices would be very similar. As a result, with that assumption there would be no parameterizations for which a real tie is employed rather than a virtual tie, because the complementary-good price cannot be negative.¹⁹

A natural and important policy question that arises is, why is a virtual tie achieved through pricing an entry-detering strategy in the network-externalities case but not in the entry-cost case? The reason is the different goals the monopolist is trying to achieve through tying in the two cases. In the network-externalities case, the monopolist's goal in tying is to force cohort 1 consumers to purchase the complementary good from the monopolist because this is what stops entry into the primary market in the second period. This can be achieved either by using a real tie, in which case cohort 1 consumers are directly forced to purchase the complementary good from the monopolist, or by a virtual tie, in which cohort 1 consumers purchase the complementary good from the monopolist because its price is set so low.

Now consider the entry-cost analysis. In that analysis, the monopolist's goal in tying is to stop the alternative producer from entering the complementary market in the first period, because in that case this is what stops entry into the primary market in the second period. This can be achieved by a real tie because the alternative producer will not enter the complementary market in the first period if it knows it cannot sell any complementary units in the first period. However, a virtual tie achieved through pricing will not work. The reason is that once the alternative producer has entered the complementary market in the first period, the monopolist's incentive is not to employ a virtual tie but rather price in such a fashion that the alternative producer sells complementary units.

¹⁹ Another reason a real tie might be used instead of a virtual tie achieved through first-period prices is that a real tie commits the monopolist to offer a tied product in the second period, whereas a virtual tie does not. This reason for employing a real tie as opposed to a virtual tie arises for parameterizations characterized by $\Delta \geq v(2N) - v(N) > \Delta/2$.

In other words, attempting to deter entry using a virtual tie is not a credible or time-consistent strategy in the entry-cost case.

A related point concerning the model of this subsection is that it is one of the few models of tying for exclusionary reasons that does not require commitment (although see footnote 19). That is, consistent with the above discussion, in this model the monopolist does not need to commit to tying its products prior to the first-period pricing decisions. Rather, the monopolist can decide on the tie at the same time prices are chosen. The reason is that, as discussed above, the goal of tying in this model is stopping the alternative producer from selling complementary units in the first period, and this can be achieved by choosing to tie when pricing decisions are made. Hence, as indicated earlier, the analysis of this subsection is consistent both with ties achieved through contracting and ties achieved through product design. The only other analysis of tying for exclusionary reasons that we know of that does not rely on commitment is a case discussed in Whinston (1990) concerning financial constraints. Similar to the analysis here, what happens is that the presence of financial constraints gives the monopolist an incentive to reduce the sales of a rival producer.

As in Section 2 one could ask whether from a social welfare standpoint there is a return to prohibiting tying, where in this case that means prohibiting both real ties and virtual ties achieved through first-period pricing (prohibiting real ties but not virtual ties achieved through first-period pricing would have no real effect when virtual ties are feasible, and would be equivalent to prohibiting both when virtual ties are not feasible). In the analysis of Proposition 3, the answer is ambiguous. The reason is that if the alternative producer sells complementary units in the first period and enters the primary market in the second, there are two countervailing effects on social welfare. It rises by $2N\Delta$ because consumers have access to the alternative producer's superior complementary product, but there is also a decrease of E_{ap} due to the alternative producer bearing the cost of entering the primary market. In turn, since $2N\Delta > E_{ap}^*$ while $2N\Delta < E_{ap}^{**}$ if $v(2N) - v(N) > 3\Delta$ (see the proof of Proposition 3), for some parameterizations in which the monopolist would tie, social welfare is increased by its prohibition, while for others it is decreased.

The intuition for this result is that in this model the alternative producer's return to entering the primary market can be excessive from a social welfare standpoint. If the monopolist does not tie and the alternative producer sells complementary units to all cohort 1 consumers in the first period, part of the alternative producer's return to entering the primary market in the second period is capturing more of that part of the second-period surplus due to network externalities and the alternative producer's first-period sales of complementary units. But that part of the second-period surplus is not a net increase in social welfare due to the alternative producer selling complementary units. The result is that the alternative producer's return to entering the primary market can exceed the increase in social welfare associated with the alternative producer's superior complementary product, which in turn means that if the monopolist ties and stops the alternative producer from selling both products, social welfare can actually increase.²⁰

□ **Applying the analysis to *U.S. v. Microsoft*.** In this subsection we argue that a variant of the model presented and analyzed in the previous subsection captures one of the Justice Department's main allegations in the antitrust case it filed against Microsoft in 1998. This allegation is that Microsoft tied its Internet Explorer browser to its Windows operating system and used a variety of other practices to increase the usage of its Internet Explorer browser in order to preserve its monopoly position in the market for personal computer operating systems.²¹ The argument

²⁰ A final point is that, as in the previous section, the results of this analysis extend to the case in which consumers prefer both the alternative producer's complementary good and its primary good, and to the case in which consumers prefer both the alternative producer's complementary good and the monopolist's primary good.

²¹ In addition to tying, the Justice Department alleged, for example, that Microsoft attempted to monopolize through the use of exclusive contracts between Microsoft and personal computer manufacturers and others, and by maintaining the applications barrier to entry by destroying Java, a programming language that allows applications to run on any operating system.

focused on what is called the “applications barrier to entry.” This refers to the idea that it is difficult for firms to enter the operating-systems market because of the large number of applications programs that run on Windows but would not run on competing operating systems.

The Justice Department’s argument was that a rival Internet browser has the potential to create competition for Windows by avoiding the applications barrier to entry. That is, programmers would have an incentive to write applications that would run on a rival browser if the rival browser were sufficiently popular. In turn, once enough such applications were written, the rival firm (or its ally) could develop an operating system compatible with the browser that would not be subject to the applications barrier to entry because of the applications written for the browser. The last step of the argument is that the operating-systems monopolist, i.e., Microsoft, to keep this sequence of events from occurring, would have an incentive to monopolize the browser market, where the tying of its operating system with its browser would be one way of achieving this goal.

A variant of the model analyzed in the previous subsection captures this argument. Let the primary good be the operating system and the complementary good be the browser. Further, let everything be the same as in the model of the previous subsection except for the following three changes. First, assume the alternative producer can enter the primary market in period 2 only if it sells complementary units in period 1. In other words, consistent with the above discussion, without selling browsers in the first period the alternative producer cannot enter the operating-systems market in the second period because of the applications barrier to entry. However, if the alternative producer sells browsers in the first period, then the applications written for the browser allow the firm to enter the operating-systems market in the second period without being subject to the applications barrier to entry. Second, we now assume that a consumer can undo ties. That is, if a consumer purchases a tied good consisting of one unit of the monopolist’s primary good and one unit of its complementary good, then a consumer can purchase a unit of the alternative producer’s complementary good and create a system consisting of the monopolist’s primary good and the alternative producer’s complementary good. This captures the idea that in the real world a consumer who purchased a bundle consisting of Windows and Explorer had the ability to add Netscape’s Navigator to the system. Third, we now incorporate into the analysis a fixed cost associated with selling complementary units, where this cost, F_c , captures real-world activities such as software support, advertising, and other fixed costs associated with selling a browser.^{22,23}

These three changes yield results similar to but not exactly the same as those we found in the previous subsection. The analyses are similar in that there is again a set of parameterizations for which (i) and (ii) of Proposition 3 hold. In particular, depending on the values of the other parameters, there can exist an intermediate range of values for E_{ap} such that the monopolist uses either a real tie or a virtual tie, the alternative producer does not enter the primary market in the second period, and the monopolist sells primary and complementary goods in each period (the exact parameter restrictions that yield such an intermediate range of values for E_{ap} are given in the mathematical supplement available upon request). In other words, the monopolist (Microsoft) ties in order to stop the alternative producer (Netscape or its ally) from eventually entering the operating-systems market, and in this way Microsoft preserves its operating-systems monopoly. Further, for some of the parameterizations in which the monopolist ties, social welfare is increased by the act of tying while for others it falls. As before, the reason tying can increase social welfare is that the alternative producer has a socially excessive return to entering the primary market.

The analyses are different in that now, as opposed to what was true in the previous subsection, there are no parameterizations for which the monopolist uses a real tie in the first period in order to

²² An analysis of this extension is available upon request. Note that one of the parameter restrictions that yields profitable tying given the fixed cost is $\Delta < c_c + (F_c/N)$, while without the fixed cost the condition is $\Delta < c_c$, which cannot hold if $c_c = 0$. This is important because in the real world, the marginal cost of producing an extra copy of a browser is close to zero.

²³ One difference between the actual case and our model is that Netscape’s Navigator had a significantly larger installed base than did Microsoft’s Internet Explorer at the time that Microsoft tied Windows and Internet Explorer. However, given that our model is characterized by network externalities, one can interpret this in terms of our model as simply being part of the reason that the alternative producer has a superior complementary product.

stop later entry into the primary market, and it is also true that a virtual tie achieved through first-period prices would not achieve this outcome. This follows from our assumption that consumers can undo ties. When, as in the previous subsection, consumers cannot undo ties, a real tie does more than simply set the price for the complementary good to zero. It also stops consumers from adding the alternative producer's complementary good independent of the price charged by the alternative producer. Hence, in the earlier analysis there were parameterizations for which the monopolist used a real tie to stop the alternative producer from later entering the primary market, while a virtual tie achieved through first-period prices would not achieve this goal. In contrast, since here consumers can undo ties, in this analysis a real tie is identical to setting the price of the complementary good to zero. As a result, in this analysis, whenever the monopolist uses a real tie to stop the alternative producer from later entering the primary market, a virtual tie works just as well.

There are three interesting aspects of this analysis. The first is that the tie can take the form of a virtual tie achieved through first-period pricing. In the actual case, Microsoft's initial behavior concerning Windows95 and Internet Explorer was to tie the two products and forbid computer manufacturers to remove Internet Explorer from their computers. Early in 1998, in the middle of the Justice Department's contempt proceedings related to that behavior, Microsoft removed the restriction on manufacturers with respect to Windows95 (later versions of Windows did not have an option to remove Internet Explorer). During this period, Internet Explorer was free for purchasers of Windows95, and the result was that Microsoft's share of the Internet browser market continued to grow even after manufacturers were allowed to remove Internet Explorer from their computers. These facts are consistent with the idea found above that in industries characterized by network externalities, real ties and virtual ties achieved through pricing can be close substitutes in forcing consumers to purchase the complementary good from the primary-market monopolist.

Given this result and the antitrust concerns associated with real ties, one might ask why Microsoft initially employed a real tie rather than a virtual tie in marketing Internet Explorer. In our model if there was even some small cost to adding a complementary product to a system that was in addition to the price of the product, then there would be some parameterizations in which a real tie would deter entry while a virtual tie would not. Our interpretation is thus that Microsoft tried to employ a real tie because in the situation it faced a real tie was somewhat more effective, but probably not much more effective, in allowing the firm to gain control of the browser market.

The second interesting aspect is that one of the parameter restrictions that yields an intermediate range of values for E_{ap} such that the monopolist ties is $v(2N) - v(N) > \Delta$, i.e., network externalities are large relative to the higher consumer benefits associated with the alternative producer's complementary product. In the real world, the network externalities associated with browsers are primarily indirect. Each browser has its own set of interfaces that programmers use when developing content for Web sites; for Web site content to display on a user's browser, the content has to conform to the browser's interfaces. Network externalities are present because if one browser becomes significantly more popular, then Web site developers will be inclined to focus on developing content that conforms to the more popular browser's interfaces; and (critically) they will be less inclined to continue incurring the costs of developing content for multiple browsers. If Web site content shifts in this manner, so that important content can be displayed only through the popular browser, this will reinforce the demand for the more popular browser. This dependency between browser interfaces and Web site content is analogous to the dependency between operating system (and browser) interfaces and applications programs. Bresnahan (2001) provides further discussion of this issue and, more important, evidence that due to these indirect effects there were strong network externalities in the browser market during the second half of the 1990s.

The third interesting aspect is our finding that the social welfare implications of our model are ambiguous. As indicated, because the alternative producer has a socially excessive return to entering the primary market, for some parameterizations social welfare decreases when the monopolist ties and deters entry, but for others tying serves to increase social welfare. In other words, our analysis suggests the theoretical possibility that Netscape's eventual entry into the

operating-systems market could have decreased social welfare, and that Microsoft's tying and stopping this entry could have, in fact, increased social welfare. Although this is just a theoretical possibility in our analysis (and we do not wish to suggest that it is empirically accurate), it does indicate that trying to develop optimal public policy in such cases may be quite a difficult task (see Section 5 for further discussion of this point).

4. Extending monopoly through strategic tying of complementary products

■ In Sections 2 and 3 we showed how a monopolist can strategically use the tying of complementary products to preserve an initial monopoly position. In this section, using two extensions of the models analyzed in the previous sections, we develop our second major finding that shows how a monopolist can strategically use the tying of complementary products to extend a monopoly position into a newly emerging market. We first consider a model closely related to that analyzed in Section 2 and discuss how tying can be used by the monopolist to "swing" or transfer its monopoly to the newly emerging market in a setting in which the newly emerging market is associated with the same complementary good as the monopolist's primary market. We then consider a model closely related to the first model analyzed in Section 3, and discuss how tying allows the monopolist to monopolize the newly emerging market in a setting in which the newly-emerging-market product is superior to a system consisting of primary and complementary units (a more detailed description and analysis of each extension appears in Carlton and Waldman (1998)).

□ **The newly-emerging-market product uses the same complementary good.** Starting from the model analyzed in Section 2 (where there was a monopolist of a primary product in period 1 and a single alternative producer that could enter the complementary market in period 1 and the primary market in period 2), we make the following changes. First, the monopolist now faces no threat of entry into its primary market, and thus tying is not needed to deter entry into that market. Second, there is now a newly emerging market that is associated with the same complementary good as does the primary market. The newly emerging market does not exist in the first period, but both the monopolist and the alternative producer can enter this market at the beginning of the second period at a cost E_n . Third, a newly-emerging-market or simply new-market unit can be either used by itself or in combination with a complementary unit. Also, similar to what is true for primary units, consumers are indifferent between a new-market unit produced by the monopolist and a new-market unit produced by the alternative producer, but they prefer the alternative producer's complementary good for their new-market systems. Fourth, as in Section 3, to simplify the analysis we now assume $N_1 = N_2 = N$ and $\delta = 1$, i.e., cohorts are of equal size and there is no discounting.²⁴

In this model, if the alternative producer could never enter the newly emerging market, the monopolist would have no incentive to deter entry into the complementary market by tying. The reason is that, given that the alternative producer can never enter the newly emerging market, the monopolist earns higher profits when the alternative producer enters the complementary market. The logic is the same as for the analogous result in Section 2 (the monopolist has no incentive to deter entry into the complementary market by tying if the alternative producer can never enter the primary market). That is, since the monopolist is able to capture some of the surplus associated with consumers preferring the alternative producer's complementary product, the monopolist's profitability rises when the alternative producer enters the complementary market.

We now consider what happens when the alternative producer has the option of entering the newly emerging market in the second period. We begin with two preliminary results concerning

²⁴ As in the model of Section 2, we also assume that the alternative producer's entry decision for the complementary market in the first period occurs after the monopolist's first-period tying decision. As a result, just as was true of the model considered in Section 2, the model considered here is best thought of as one concerning tying achieved through product design rather than tying achieved through contracting.

what happens in the second period as a function of the alternative producer's behavior in the complementary market. First, if the alternative producer enters the complementary market in the first period and E_n is sufficiently small, then only the alternative producer will enter the newly emerging market in the second period. The reason is that the alternative producer will necessarily enter the newly emerging market given that it has a superior complementary product (if the alternative producer expects the monopolist to enter, then it enters anyway because entry allows the firm to capture more of the surplus associated with its superior complementary product), while because the monopolist's complementary product is inferior, it does not enter the newly emerging market if it expects the alternative producer to enter. Second, a similar logic yields that if the alternative producer never enters the complementary market and the entry cost for the newly emerging market is sufficiently small, then only the monopolist enters the newly emerging market in the second period.

Our main result, which builds on the two preliminary results above, concerns the monopolist's choice of whether or not to tie its primary and complementary products.²⁵ In particular, if the entry cost for the newly emerging market is sufficiently small, then the monopolist sometimes ties its primary and complementary goods because this allows the firm to extend its monopoly position into the newly emerging market. The logic here is as follows. If the monopolist offers individual products and as a result the alternative producer enters the complementary market in the first period, then from above we know the alternative producer monopolizes the newly emerging market in the second period. But suppose the monopolist ties. Then the alternative producer has no incentive to enter the complementary market in the first period. Further, the alternative producer's return for being active in the complementary market in the second period is lower for two reasons. First, if it is active in the complementary market in the second period, it now bears the complementary market entry cost in that period. Second, it cannot sell any complementary units in the second period for use in primary-market systems. If these costs are sufficiently large, then the alternative producer will never enter the complementary market. In turn, if this is the case, then the monopolist will tie because from above we know the monopolist will monopolize the newly emerging market if the alternative producer never enters the complementary market.

It should be clear that the argument of this subsection is closely related to that of Section 2. In Section 2 the monopolist tied its primary and complementary goods and in this way reduced the alternative producer's second-period return from being active in the primary and complementary markets. The result was that the alternative producer never entered either the primary or complementary market and the monopolist preserved its monopoly position in the primary market in the second period. Here, the monopolist ties its primary and complementary goods and in this way reduces the alternative producer's second-period return from being active in the newly emerging and complementary markets. The result is that the alternative producer never enters either the newly emerging or complementary market, and the monopolist establishes a monopoly position in the newly emerging market in the second period.

One interesting difference between the argument presented here and the argument of Section 2 is that here the social welfare implications are ambiguous. That is, social welfare is increased by a prohibition on tying for some of the parameterizations in which the monopolist ties, but for other such parameterizations social welfare is decreased by a prohibition on tying. The logic behind this result is similar to the logic for the similar result in Section 3, i.e., in each case the result stems from a socially excessive return to entry. In the above analysis, if the monopolist offers individual products and the alternative producer enters the complementary market in the first period, then the alternative producer monopolizes the newly emerging market in the second period. That is, part of the alternative producer's return to entering the complementary market in the first period is the return to monopolizing the newly emerging market in the second period.

²⁵ When the monopolist ties its primary and complementary goods, as opposed to what was true in Section 2, here we allow the monopolist to offer the complementary good as an individual product in the second period. This simply means that the monopolist can sell complementary units for use in new-market systems even if it ties its primary and complementary goods.

But since this part of the return does not represent a net increase in social welfare, the alternative producer would sometimes enter the complementary market in the first period even when the entry cost is so high that entry reduces social welfare. In such a case, prohibiting tying decreases social welfare because it results in inefficient entry.

□ **The newly-emerging-market product is superior to a primary-complementary-good system.** In this subsection we explore a second avenue through which linkages between a primary market and a newly emerging market allow a monopolist to extend its monopoly position to the newly emerging market. In particular, we consider a variant of the first model analyzed in Section 3 involving network externalities, and show how our analysis applies when a newly-emerging-market product that is also subject to network externalities is superior to a system consisting of primary and complementary goods. Our main result is that by tying its primary and complementary products, the initial monopolist can sometimes establish a monopoly position in the newly emerging market in the second period and thus retain its monopoly profits in the second period even after its primary product becomes obsolete (previous articles that have studied the obsolescence issue include Levinthal and Purohit (1989), Waldman (1993, 1996), and Choi (1994)).

We make the following three changes to the first model analyzed in Section 3. First, as in the previous subsection, the monopolist now faces no threat of entry into its primary market, and thus tying is not needed to deter entry into that market. Second, our focus here is on parameterizations characterized by strong network externalities, i.e., $v(2N) - v(N) > \Delta$. Third, at the beginning of the second period each firm can invest E_n and acquire the ability to produce a new-market product, where a producer's new-market product is a perfect substitute for a system consisting of a primary unit and a unit of the producer's complementary good, but it has a lower marginal cost of production. Note that because of network externalities and this perfect substitutability, a consumer's gross benefit from a producer's new-market product in the second period is positively related to the number of consumers of the firm's complementary product in the first. Similarly, a consumer's gross benefit from a system in the first period is positively related to the number of consumers in the second period who purchase new-market products built by the same producer who built the system's complementary good.²⁶

We begin with two preliminary results similar to the two preliminary results in the previous subsection. First, if all cohort 1 consumers purchase the monopolist's complementary product and E_n is sufficiently small, then in the second period only the monopolist invests in the new-market technology and all cohort 2 consumers purchase only the monopolist's new-market product. The logic here is as follows. Because cohort 2 consumers prefer new-market products produced by the first-period seller of complementary units (this follows from $v(2N) - v(N) > \Delta$), if all cohort 1 consumers purchased complementary units from the monopolist and E_n is sufficiently small, then the monopolist invests whether or not it expects the alternative producer to invest. Further, because the alternative producer's new-market product is inferior in this case, the alternative producer will not invest if it expects the monopolist to invest. The result is that if all cohort 1 consumers purchase the monopolist's complementary product and E_n is sufficiently small, then only the monopolist invests in the second period. Second, a similar logic yields that if all cohort 1 consumers purchase the alternative producer's complementary product and E_n is sufficiently small, then in the second period only the alternative producer invests and all cohort 2 consumers purchase only the alternative producer's new-market product.

Our main result is similar to the main result in the previous subsection. If E_n is sufficiently small, then in the first period the monopolist ties in order to stop the alternative producer from selling complementary units, where the return to this behavior is that the firm establishes a monopoly position in the newly emerging market in the second period. In contrast to what was

²⁶ As was true in Section 3, results here are independent of whether the monopolist chooses first-period prices after deciding whether or not to tie or whether the decisions are made simultaneously. Hence, as also was true in Section 3, the analysis that follows applies equally well to ties achieved through product design as to ties achieved through contracting.

true in the previous subsection, however, we find that as in Section 3, the tie now can take the form of either a real tie or a virtual tie achieved through pricing. As in Section 3, by a virtual tie achieved through pricing we mean that the monopolist offers individual products but charges a sufficiently low price for the complementary good that the alternative producer chooses not to sell complementary units.

The logic for why the monopolist has an incentive to tie in this setting is closely related to the two preliminary results described above. If the alternative producer sells complementary units in the first period, then from above we know the alternative producer monopolizes the newly emerging market in the second period, and, not surprisingly, this results in a decrease in overall monopoly profitability. To stop this from occurring, in the first period the monopolist uses either a real tie or a virtual tie achieved through pricing to ensure that cohort 1 consumers purchase complementary units from the monopolist. From above we know this increases monopoly profitability, because forcing cohort 1 consumers to purchase complementary units from the monopolist results in the firm monopolizing the newly emerging market in the second period.

As in Section 3, one could ask whether from a social welfare standpoint there is a return to prohibiting tying where this means prohibiting both real ties and virtual ties achieved through first-period pricing. The answer is that for the parameterizations in which the monopolist has an incentive to tie, a prohibition on tying unambiguously increases social welfare. The logic is straightforward. If the monopolist ties, then cohort 1 consumers purchase the monopolist's complementary product, only the monopolist invests in the second period, and both cohorts of consumers forgo Δ . In contrast, if the monopolist does not tie, then cohort 1 consumers purchase the alternative producer's complementary product, only the alternative producer invests in the second period, and both cohorts of consumers receive Δ . Since from a social welfare standpoint the only difference between the cases is that both cohorts of consumers forgo Δ when the monopolist ties, social welfare is unambiguously increased by a prohibition on tying.

5. Conclusion

■ Most previous analyses of tying have focused either on the ability of tying to achieve price discrimination or its ability to foreclose competition in the tied market. In contrast, our focus is on the use of tying to preserve and extend a monopoly position in the tying market by deterring the entry of efficient producers. In particular, we present a series of analyses in which a firm that is currently a monopolist in its primary market uses tying of a complementary good to deter entry into the complementary market and either the primary market or a newly emerging market. Depending on the model, the result is that the monopolist either preserves its monopoly in the primary market or transfers it to a newly emerging market. We show how this works both in models characterized by an entry cost for the complementary good and in models characterized by network externalities. Our analysis also explains how a dominant firm can use tying to remain dominant in an industry undergoing rapid technological change.

Although a full analysis of the antitrust implications of our analysis is beyond the scope of this article, we would like to caution that trying to turn the theoretical possibility for harm shown here into a prescriptive theory of antitrust enforcement is a difficult task.²⁷ For example, the courts would have to weigh any potential efficiencies from the tie with possible losses due to foreclosure, which by itself is challenging due to the difficulty of measuring both the relevant efficiencies and the relevant losses. Note that one reason for this difficulty is that, as we have shown, even focusing solely on foreclosure can yield ambiguous results on how tying affects social welfare. That is, there are some situations in which tying used for foreclosure can actually increase social welfare because the alternative producer has a socially excessive return to entry. Another important but complicated issue concerns whether raising the rate of return is desirable in industries undergoing

²⁷ For a full analysis of the antitrust implications of the type of strategic behavior analyzed here, see Carlton and Waldman (1998) and Carlton (2001a,b). Other analyses of antitrust and the strategic effects of tying appear in Gilbert and Katz (2001), Klein (2001), and Whinston (2001).

rapid technological change. If, as empirical studies appear to show (see, e.g., Mansfield et al. (1977), Bernstein and Nadiri (1988), Mansfield (1991), and Jones and Williams (1998)), the social rate of return from innovation exceeds the private rate of return, strategic behavior that entrenches monopoly could be welfare enhancing. But this poses a particularly complicated dynamic welfare problem to analyze, in that strategic behavior that entrenches monopoly could raise the rate of return and thereby encourage innovation early in an industry's evolution, but such behavior could dampen incentives for subsequent innovations.

Although there are many directions in which our analysis could be extended, there are two that are salient. First, it might be of interest to analyze a setting in which the monopolist can control the speed of innovation and product lifetimes. Our conjecture is that in such a setting, a primary-market monopolist would sometimes preserve and extend its monopoly by both introducing new products quickly and tying each new generation of its primary and complementary products. The logic is that, consistent with the discussion in Section 2, tying is likely to be a more effective tool in markets in which product lifetimes are short. Second, it might be of interest to explore the extent to which our arguments apply to merger activity. Our conjecture is that many of our arguments apply to a monopolist of a primary product merging with a complementary-good producer with significant market power. The logic is that such a merger may help the monopolist preserve its monopoly by eliminating a potential rival who has a strong incentive to enter the primary market, although the welfare consequences of such a merger are likely to be theoretically ambiguous.

Appendix

■ Proofs of Propositions 1–3 and Lemma 1 follow.

Proof of Proposition 1. Proposition 1 can be thought of as a corollary of Proposition 3 in Whinston (1990) and the proof is thus omitted. See Carlton and Waldman (1998) for a formal proof.

Proof of Lemma 1. Suppose the monopolist offers independent products, the alternative producer enters the complementary market in period 1, and the alternative producer does not enter the primary market in period 2. Then the prices that emerge each period evenly split the surplus associated with consumers preferring the alternative producer's version of the complementary good. This means that in each period the alternative producer charges $c_c + (\Delta/2)$ for its complementary product, the monopolist charges $V - c_c + (\Delta/2)$ for its primary product, the monopolist charges any price greater than or equal to c_c for its complementary product, and consumers purchase the primary product from the monopolist and the complementary product from the alternative producer. This means $\pi_{a2}^c = N_2\Delta/2$.

Now suppose the alternative producer entered the complementary market in period 1 and the primary market in period 2. We consider the case in which the monopolist offers independent products, but the second-period profitabilities for the two firms are the same if the monopolist offers a tied product. For the primary product, Bertrand competition yields that each firm charges a price equal to c_p and sales are split between the two firms. For the complementary product, Bertrand competition yields that the monopolist charges c_c , the alternative producer charges $c_c + \Delta$, and cohort 2 consumers purchase complementary units from the alternative producer.²⁸ This yields $\pi_{a2}^{pc} = N_2\Delta - E_{ap}$. Let $E_{ap}^* = N_2\Delta/2$. We now have $\pi_{a2}^{pc} > \pi_{a2}^c$ if $E_{ap} < E_{ap}^*$, while $\pi_{a2}^{pc} < \pi_{a2}^c$ if $E_{ap} > E_{ap}^*$. *Q.E.D.*

Proof of Proposition 2. Suppose the monopolist offers a tied product. There are five possibilities. First, the alternative producer never enters either market, in which case $\pi_m = (N_1 + \delta N_2)[V - c_p - c_c] - E_m$ and $\pi_a = 0$. Second, the alternative producer enters the complementary market in either period 1 or period 2 and never enters the primary market. Because the monopolist is only offering a tied product, the alternative producer would be unable to sell any complementary units if it only entered the complementary market, and thus in this case $\pi_a < 0$. Third, the alternative producer enters the primary market in period 2 and never enters the complementary market. Because the monopolist is offering a tied product, the alternative producer would be unable to sell any primary units in period 2 if it only entered the primary market, and thus in this case $\pi_a = -\delta E_{ap}$. Fourth, the alternative producer enters the primary market in period 2 and enters the complementary market in period 2. In the second period, Bertrand competition yields that the monopolist charges $c_p + c_c$ for its system, the alternative producer charges an aggregate price of $c_p + c_c + \Delta$ for its two products, and consumers purchase both primary and complementary products from the alternative producer. Thus, in this case $\pi_m = N_1[V - c_p - c_c] - E_m$ and $\pi_a = \delta(N_2\Delta - E_{ap} - E_{ac})$. Fifth, the alternative producer enters the primary market in period 2 and the complementary market in period 1. Using the same logic as for the fourth possibility yields $\pi_m = N_1[V - c_p - c_c] - E_m$ and $\pi_a = \delta[N_2\Delta - E_{ap}] - E_{ac}$.

²⁸ There are other price pairs consistent with Bertrand competition in which the monopolist charges a price for the complementary good that is below its marginal cost. Here and in later analyses, we rule out pricing of this sort. Formally, any trembling-hand-type refinement concerning consumer purchase decisions would rule out such pricing.

Suppose the monopolist offers individual products. There are six possibilities. First, the alternative producer never enters either market, in which case $\pi_m = (N_1 + \delta N_2)[V - c_p - c_c] - E_m$ and $\pi_a = 0$. Second, the alternative producer enters the complementary market in period 1 and never enters the primary market. From the proof of Lemma 1, we know that in this case $\pi_m = (N_1 + \delta N_2)[V - c_p - c_c] + (N_1 + \delta N_2)(\Delta/2) - E_m$ and $\pi_a = (N_1 + \delta N_2)(\Delta/2) - E_{ac}$. Third, the alternative producer enters the complementary market in period 2 and never enters the primary market. Using the same logic as in Lemma 1, we know that in this case $\pi_m = (N_1 + \delta N_2)[V - c_p - c_c] + \delta N_2(\Delta/2) - E_m$ and $\pi_a = \delta N_2(\Delta/2) - \delta E_{ac}$. Fourth, the alternative producer enters the primary market in period 2 and never enters the complementary market. Bertrand competition means that in period 2 both firms charge c_p for the primary product, which in turn means $\pi_a = -\delta E_{ap}$. Fifth, the alternative producer enters the primary and complementary markets in period 2. In the second period, Bertrand competition yields that both firms charge c_p for the primary product, the monopolist charges c_c for its complementary product while the alternative producer charges $c_c + \Delta$ for its complementary product, and consumers purchase complementary units from the alternative producer while purchases of primary units are split across the two firms. Thus, in this case $\pi_m = N_1[V - c_p - c_c] - E_m$ and $\pi_a = \delta(N_2\Delta - E_{ap} - E_{ac})$. Sixth, the alternative producer enters the complementary market in period 1 and the primary market in period 2. Pricing in the second period is as in the fifth case above. In the first period, the prices that emerge evenly split the surplus associated with consumers preferring the alternative producer's version of the complementary product. This means the alternative producer charges $c_c + (\Delta/2)$ for its complementary product, the monopolist charges $V - c_c + (\Delta/2)$ for its primary product, the monopolist charges any price greater than or equal to c_c for its complementary product, and consumers purchase the primary product from the monopolist and the complementary product from the alternative producer. Thus, in this case $\pi_m = N_1[V - c_p - c_c] + N_1(\Delta/2) - E_m$ and $\pi_a = N_1(\Delta/2) + \delta N_2\Delta - E_{ac} - \delta E_{ap}$.

Let $E_{ac}^* = N_2\Delta - E_{ap}$ and $E_{ac}^{**} = N_1(\Delta/2) + \delta N_2\Delta - \delta E_{ap}$, and suppose $E_{ac}^* < E_{ac} < E_{ac}^{**}$. If the monopolist ties, then from above we know the alternative producer never enters either market. Further, $\pi_m = (N_1 + \delta N_2)[V - c_p - c_c] - E_m$ and $\pi_a = 0$. If the monopolist offers individual products and given $E_{ap} < E_{ap}^* = N_2\Delta/2$ and $N_1 > (1 - \delta)N_2$ (see footnote 7), then from above we know the alternative producer enters the complementary market in period 1 and the primary market in period 2. Further, $\pi_m = N_1[V - c_p - c_c] + N_1(\Delta/2) - E_m$ and $\pi_a = N_1(\Delta/2) + \delta N_2\Delta - E_{ac} - \delta E_{ap}$. Given $\delta N_2(V - c_p - c_c) > N_1(\Delta/2)$, we know $(N_1 + \delta N_2)(V - c_p - c_c) - E_m > N_1(V - c_p - c_c) + N_1(\Delta/2) - E_m$. Thus, in this case the unique equilibrium is the monopolist offers a tied product and the alternative producer never enters either market. *Q.E.D.*

Proof of Proposition 3. Here we present the proof for parameterizations characterized by $v(2N) - v(N) > \Delta$. The proof for parameterizations characterized by $\Delta \geq v(2N) - v(N) > \Delta/2$ is available from the authors upon request. Suppose all cohort 1 consumers purchase complementary units from the monopolist. There are two possibilities for what happens in period 2. First, the alternative producer enters the primary market in period 2. Given our assumption that purchase decisions are made as if consumers could coordinate behavior, Bertrand competition in this case yields that both firms will charge c_p for a primary unit, the alternative producer will charge c_c for a complementary unit, the monopolist will charge $c_c + v(2N) - v(N) - \Delta$ for a complementary unit, and consumers purchase complementary units from the monopolist while purchases of primary units may be split between the firms (if the monopolist is offering a tied product, then all primary units are purchased from the monopolist). This yields $\pi_{m2} = N[v(2N) - v(N) - \Delta]$ and $\pi_{a2} = -E_{ap}$.

Second, the alternative producer does not enter the primary market in period 2. Given our assumption that purchase decisions are made as if consumers could coordinate behavior, consumers purchase both primary and complementary units from the monopolist. In particular, the alternative producer charges c_c for a complementary unit, while the monopolist charges an aggregate price of $V + v(2N)$ for a system (if the monopolist sells individual products, then the price for the primary product is in the interval $[V + \Delta + v(N) - c_c, V + v(2N)]$ while the complementary-good price equals $V + v(2N)$ minus the primary-good price). This yields $\pi_{m2} = N[V + v(2N) - c_p - c_c]$ and $\pi_{a2} = 0$. Comparing this expression for the alternative producer's second-period profit with the expression above yields that if all cohort 1 consumers purchase complementary units from the monopolist, then the alternative producer does not enter the primary market in period 2, cohort 2 consumers purchase both primary and complementary goods from the monopolist, $\pi_{m2} = N[V + v(2N) - c_p - c_c]$, and $\pi_{a2} = 0$.

Suppose all cohort 1 consumers purchase complementary units from the alternative producer (this will only be the case if the monopolist offers individual products). There are again two possibilities for what happens in period 2. First, the alternative producer enters the primary market in period 2. Given our assumption that purchase decisions are made as if consumers could coordinate behavior, Bertrand competition in this case yields that both firms will charge c_p for a primary unit, the monopolist will charge c_c for a complementary unit, the alternative producer will charge $c_c + \Delta + v(2N) - v(N)$ for a complementary unit, and consumers purchase complementary units from the alternative producer while purchases of primary units may be split between the firms. This yields $\pi_{m2} = 0$ and $\pi_{a2} = N[\Delta + v(2N) - v(N)] - E_{ap}$.

Second, the alternative producer does not enter the primary market in period 2. By assumption, the prices that emerge evenly split the surplus associated with consumers preferring the alternative producer's superior complementary product. This means the alternative producer charges $c_c + [(\Delta + v(2N) - v(N))/2]$ for a complementary unit, the monopolist charges c_c or more for a complementary unit, the monopolist charges $V + \Delta + v(2N) - c_c - [(\Delta + v(2N) - v(N))/2]$ for a primary unit, and consumers purchase primary units from the monopolist and complementary units from the alternative producer. This yields $\pi_{m2} = N[V + \Delta + v(2N) - c_p - c_c - [(\Delta + v(2N) - v(N))/2]]$ and $\pi_{a2} = N[(\Delta + v(2N) - v(N))/2]$. Let $E_{ap}^{**} = N[(\Delta + v(2N) - v(N))/2]$, and for these parameterizations let $E_{ap}^* = 0$. Comparing this expression for the alternative producer's second-period profit with the expression above yields that if $E_{ap}^* < E_{ap} < E_{ap}^{**}$ and all cohort 1

consumers purchase complementary units from the alternative producer, then the alternative producer enters the primary market in period 2, cohort 2 consumers purchase complementary units from the alternative producer while purchases of primary units may be split between the firms, $\pi_{m2} = 0$, and $\pi_{a2} = N[\Delta + v(2N) - v(N)] - E_{ap}$.

Now consider period 1. Suppose the monopolist ties in period 1. If all cohort 1 consumers purchase complementary units from the monopolist, then from above we know that in period 2 all cohort 2 consumers will also purchase complementary units from the monopolist. Let P_s denote the price the monopolist charges for a system. Given that a cohort 1 consumer's net benefit from purchasing a system from the monopolist equals $V + v(N_{m1} + N_{m2}) - P_s$, for any P_s that satisfies $P_s \leq V + v(2N)$, each cohort 1 consumer's utility is maximized by having every cohort 1 consumer purchase a system (if $P_s = V + v(2N)$, then each cohort 1 consumer is indifferent between having all purchase and not purchasing). Similarly, for any P_s that satisfies $P_s > V + v(2N)$, each cohort 1 consumer's utility is maximized by not purchasing. Hence, since purchase decisions are made as if consumers could coordinate behavior and since if all cohort 1 consumers purchase the resulting second-period profit is independent of the first-period price, the monopolist sets $P_s = V + v(2N)$.²⁹ This, in turn, yields $\pi_{m1} = N[V + v(2N) - c_p - c_c] - E_m$, $\pi_{m2} = N[V + v(2N) - c_p - c_c]$, and $\pi_m = 2N[V + v(2N) - c_p - c_c] - E_m$.

Suppose the monopolist offers individual products in period 1. Let P_p denote the monopolist's price for its primary product, P_c denote the monopolist's price for its complementary product, and P_{ac} denote the alternative producer's price for its complementary product. A cohort 1 consumer's net benefit from purchasing a system consisting of one unit of the monopolist's primary product and one unit of the alternative producer's complementary product is $V + \Delta + v(N_{a1} + N_{a2}) - P_p - P_{ac}$. This means that if the alternative producer is to sell any complementary units in period 1, the alternative producer's price for complementary units must satisfy $P_{ac} \leq V + \Delta + v(2N) - P_p$. Given this, if the alternative producer sells complementary units in the first period, its overall profit cannot exceed what it earns if it sets $P_{ac} = V + \Delta + v(2N) - P_p$ and sells complementary units to all cohort 1 consumers, i.e., $\pi_a \leq N[V + \Delta + v(2N) - P_p - c_c] + N[\Delta + v(2N) - v(N)] - E_{ap}$. Further, let P^* satisfy $N[V + \Delta + v(2N) - P^* - c_c] + N[\Delta + v(2N) - v(N)] - E_{ap} = 0$. We now have that the alternative producer can only sell complementary units in the first period if $P_p \leq P^*$.

If the monopolist offers individual products in period 1, there are three possibilities. First, the alternative producer sells complementary units to some but not all cohort 1 consumers in the first period. There are two cases. First, the alternative producer does not enter the primary market in the second period. Consider a cohort 1 consumer who purchased the alternative producer's complementary product. This consumer's first-period utility is given by $V + \Delta + v(N_{a1} + N_{a2}) - P_p - P_{ac} \geq V + v(N_{m1} + N_{m2}) - P_p - P_c$ (if this inequality did not hold, the consumer could have increased his utility by purchasing the monopolist's complementary product).³⁰ But if this condition holds, then all cohort 1 consumers purchasing the alternative producer's complementary product is also equilibrium behavior, and under this alternative set of purchase strategies this consumer's first-period utility is given by $V + \Delta + v(2N) - P_p - P_{ac} > V + \Delta + v(N_{a1} + N_{a2}) - P_p - P_{ac}$. Given our assumption that purchase decisions are made as if consumers could coordinate behavior, we have just shown that it cannot be the case that some but not all cohort 1 consumers purchase complementary units from the alternative producer in the first period, and the alternative producer does not enter the primary market in the second period. Second, the alternative producer enters the primary market in the second period. This case is ruled out using an argument similar to that used to rule out the first case.

Second, the alternative producer sells complementary units to all cohort 1 consumers in the first period. In this case, $\pi_{m1} = N[P_p - c_p] - E_m$, and from above we know $\pi_{m2} = 0$. This means $\pi_m = N[P_p - c_p] - E_m$, and since we also know from earlier that $P_p \leq P^*$, we have $\pi_m \leq N[P^* - c_p]$. Given P^* satisfies $N[V + \Delta + v(2N) - P^* - c_c] + N[\Delta + v(2N) - v(N)] - E_{ap} = 0$, we know $P^* < [V + \Delta + v(2N) - c_c] + [\Delta + v(2N) - v(N)]$. Thus, $\pi_m < N[V + \Delta + v(2N) - c_p - c_c] + N[\Delta + v(2N) - v(N)] - E_m$. Given $V + v(N) - c_p - c_c > 2\Delta$, this expression for overall monopoly profit is strictly less than overall monopoly profit when the monopolist ties. Thus, the monopolist's best tying strategy dominates any strategy in which the monopolist offers individual products, and the alternative producer sells complementary units to all cohort 1 consumers in the first period.

Third, the alternative producer sells no complementary units in the first period. Clearly, the best the monopolist can do in this case is sell primary and complementary units to all consumers in both periods and extract all the surplus. When it can do this, $\pi_m = 2N[V + v(2N) - c_p - c_c] - E_m$, i.e., overall monopoly profit is the same as with tying. Achieving this result requires $P_c = V + v(2N) - P_p$. Assuming that strictly negative prices are not feasible, there are two cases. First, suppose $P^* > V + v(2N)$. If the monopolist sets $P_p \geq P^*$, then $P_c = V + v(2N) - P_p$ yields $P_c < 0$, which is not a feasible strategy. If the monopolist sets $P_p < P^*$ and $P_c = V + v(2N) - P_p$, then the alternative producer's best response is to set P_{ac} in such a fashion that cohort 1 consumers purchase complementary units from the alternative producer. Hence, if $P^* > V + v(2N)$, then the monopolist cannot achieve $\pi_m = 2N[V + v(2N) - c_p - c_c] - E_m$. Second, suppose $P^* \leq V + v(2N)$. If the monopolist sets $P_p > V + v(2N)$, then $P_c = V + v(2N) - P_p$ yields $P_c < 0$, which is not a feasible strategy. If the monopolist sets $P_p < P^*$ and $P_c = V + v(2N) - P_p$, then the alternative producer's best

²⁹ Because price is a continuous variable, for any P_s strictly below $V + v(2N)$, there is a higher value for P_s that increases the monopolist's overall profit. This means that if the monopolist ties, the unique equilibrium to the subsequent subgame is characterized by $P_s = V + v(2N)$.

³⁰ For this step of the proof we are assuming that each cohort of consumers consists of a continuum of individuals of mass N . By assuming this, we ensure that no single cohort 1 consumer's first-period purchase decisions determine the equilibrium to the second-period subgame.

response is again to set P_{ac} in such a fashion that cohort 1 consumers purchase complementary units from the alternative producer. However, suppose the monopolist sets $P^* \leq P_p \leq V + v(2N)$ and $P_c = V + v(2N) - P_p$. Then $P_c \geq 0$ and the alternative producer's best response is to price in such a way that the alternative producer sells no complementary units in the first period (if $P_p = P^*$, then the alternative producer is indifferent between pricing in this fashion and pricing such that it sells complementary units to all cohort 1 consumers in the first period). In other words, if $P^* \leq V + v(2N)$, then there exists one or more price pairs for which overall monopoly profit is the same as with tying.

In summary, there are two parameter regimes. If $P^* > V + v(2N)$, then there is a unique equilibrium in which the monopolist offers a tied product, the alternative producer does not enter the primary market in the second period, and consumers in both cohorts purchase both primary and complementary goods from the monopolist. If $P^* \leq V + v(2N)$, then there are multiple equilibria. One equilibrium is the same as when $P^* > V + v(2N)$. The other equilibria are identical to the tying equilibrium, except that in the first period the monopolist sells individual products and charges a high price for the primary product and a low price for the complementary product.

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