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COMPATIBILITY AND BUNDLING OF COMPLEMENTARY GOODS IN A DUOPOLY*

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This paper presents a simple model of compatibility and bundling in industries where consumers assemble several necessary components into a system that is close to their ideal. We show that, for a wide range of parameters, firms will choose to produce compatible components but will offer discounts to consumers who purchase all components from the same firm. However, firms would be better off if they could commit not to provide such discounts. Furthermore, the equilibrium tends to involve socially excessive bundling. Finally, mixed bundling strategies tend to increase the range of parameters over which socially excessive standardization occurs.

I. INTRODUCTION

IN MANY industries, firms must decide whether to make their product(s) compatible with those sold by their rivals. While such 'standardization' can limit product differentiation and thus increase price competition (Farrell and Saloner [1986]), it has been argued that it also increases industry demand. This upward shift in demand is usually modelled as resulting from positive network externalities, i.e. consumers' enjoyment of the product(s) is assumed to increase with the number of consumers who purchase compatible goods (see, for example, Katz and Shapiro, [1985 and 1986] and Farrell and Saloner, [1985, 1986b and 1990]).

These positive network effects can arise because of rather different mechanisms. For example, consumers might value compatibility because it gives them access to a larger physical network (e.g. telecommunications), because it reduces their costs of switching between suppliers to get a better price, or because a larger network size achieved through compatibility leads to a more abundant or varied supply of complementary goods. These mechanisms are worth studying in some detail since they may have very different implications for the strategic behavior of the firms involved in the industry.

In that spirit, a recent literature has examined firms' incentives to standardize components in industries where consumers try to assemble a

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number of components into a system that meets their specific needs. While some authors have focused on situations where each component is sold by an independent firm (Chou and Shy [1989], Church and Gandal [1989], Matutes and Regibeau [1989]), two papers have discussed the case where each firm supplies all the components necessary to form a 'system'. Matutes and Regibeau [1988] showed that such fully integrated firms have strong incentives to produce components that are compatible with those of their rivals. This basic model was extended considerably by Economides [1989], who demonstrated that their conclusion still holds for n firms and a more general specification of demand.[1]

In these two papers, the firms price components separately, i.e. they are not allowed to offer a discount to the consumers who purchase the whole system (or "bundle") from them. However, a quick look through a daily newspaper will convince the reader that bundling is indeed a common practice in markets where consumers care about "systems": PC packages that include the computer, the monitor and maybe a printer are routinely priced at a discount compared to the prices of the individual items; the same is true for complete stereo systems, cameras with a lens, etc.

The present paper extends the original analysis of Matutes and Regibeau [1988] to allow firms to price a "bundle" of their components separately from their individual components. Such "mixed bundling" significantly changes the nature of the perfect Nash equilibrium. For a wide range of parameters the bundling subgame has the structure of a prisoner's dilemma in the sense that two firms producing compatible components choose to offer a discount on their full system even though they would be better off if they could agree not to bundle. In addition, from a social welfare perspective, the firms' propensity to bundle is excessive. We also show that the availability of bundling strategies reduces the range of parameters for which firms decide to produce compatible components and tends to increase the range of parameters for which socially excessive standardization occurs. Our analysis also suggests that the results of the literature on monopoly bundling cannot be extended to other market structures in any straightforward manner.

The rest of the paper is organized as follows. The basic model is described in section II, and the results and implications for welfare are presented in sections III and IV. In section V, we discuss the robustness of our results and compare them to the literature on monopoly bundling and on tie-ins.

II. MODEL

We consider a duopoly where both firms produce the two components of a system (e.g. hardware and software). Each component produced by firm A is differentiated from the equivalent component sold by firm B.

[1] See also Einhorn [1990] for the case where the firms' components are vertically differentiated.

Consumers differ in their ideal specification of the components. More precisely, it is assumed that the consumers are uniformly distributed over a unit square. As shown in Figure 1, consumers can potentially choose between four systems. Two 'pure' systems, AA and BB, include only components made by the same firm and are 'located' at the South-West and North-East corners respectively. Two 'mixed' or 'hybrid' systems, AB and BA, include one component from each firm and are respectively located at the North-West and South-East corners. Each consumer purchases at most one unit of the system that she prefers at the given prices and does not derive any satisfaction from consuming only one of the two components. A consumer who purchases one unit of the system made of component 1 from firm i and component 2 from firm j obtains a surplus of

$$C-d_{1i}-d_{2j}-P_{1i}-P_{2j}$$

where $i = A, B$; $j = A, B$; C is every consumer's reservation price for one unit of its ideal system; P_{kj} is the price of the k^{th} component sold by firm j; and d_{kj} is the "distance" between the consumer's ideal specification of the k^{th} component and firm j's version of that component.

The competition between the two firms is modelled as a three-stage game. In the first stage, each firm chooses whether or not to make its components compatible with the components sold by its rival. As in Matutes and Regibeau [1988], one can distinguish between cases where compatibility can

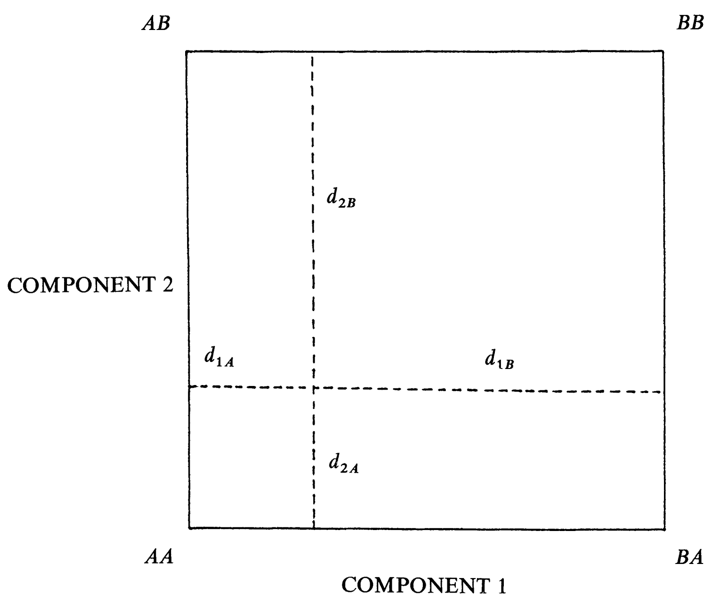

Figure 1

be enforced unilaterally (e.g. by building an adaptor) and cases where the agreement of both firms is required for compatibility to prevail (the 'consensus' case).[2] In the second stage, each firm chooses one of three marketing strategies. A firm can sell its components separately (a "pure component" strategy), sell them only as a system ("pure bundling") or do both ("mixed bundling").

It is important to realize that the marketing choices that are effectively available to a firm depend on the previous compatibility decisions. If the firms have chosen different compatibility standards, then all three marketing strategies are equivalent to pure bundling since consumers can only choose between firm *A*'s complete system and firm *B*'s complete system. In the third stage of the game, both firms simultaneously set the prices of their components and/or the price of their bundle, taking the initial compatibility and marketing choices as given. As firms will typically offer their "systems" at a discount with respect to the prices of the individual components, it is necessary to assume that consumers cannot "unbundle" the systems and resell their components.[3]

The three-stage structure of the game makes sense if the bundling decisions are harder to reverse than the pricing decisions. While this would likely be the case whenever bundling involves some changes in the product design and/or packaging, one can also imagine situations where "bundling" only involves offering a discount on the components sold as a "system". In such a case, it would be more appropriate to consider a two-stage game where the two firms simultaneously set their prices. Such a specification is discussed in section V.

Each component is produced at constant (zero) marginal cost. Compatibility and bundling are also assumed to be achieved costlessly.[4] The perfect Nash equilibrium of the game is characterized by solving the game backwards. The following section discusses the optimal marketing strategies of the firms. Compatibility choices are examined in section IV.

III. EQUILIBRIA OF THE MARKETING SUBGAME

In Matutes and Regibeau [1988], we used a similar framework to analyze the behavior of firms who can choose between selling components that are

[2] Only two-way compatibility is considered in this paper, i.e. if *A*'s components are compatible with *B*'s, the converse must also hold.

[3] The common justification for this assumption is that "unbundling" might itself be costly (e.g. if hard disks and add-on cards must be removed from a PC system and repackaged) or that it is costly for consumers to gain access to the necessary resale channels. In practice, it is reasonable to expect that the threat of resale places an upper bound on the discount that can be offered on the "bundle". This discount can still be significant however as shown, for example, by Tandy Corporation's offering of complete "systems" at 75% of the price of its separate components (advertisement in the business section of the *Chicago Tribune*, October 25, 1990).

[4] Positive costs of standardization are introduced when we discuss welfare, in section IV.

compatible with those sold by their rival and offering incompatible elements. As we did not allow firms to sell complete systems at a discount, firms selling compatible components were in fact limited to a "pure component" strategy.

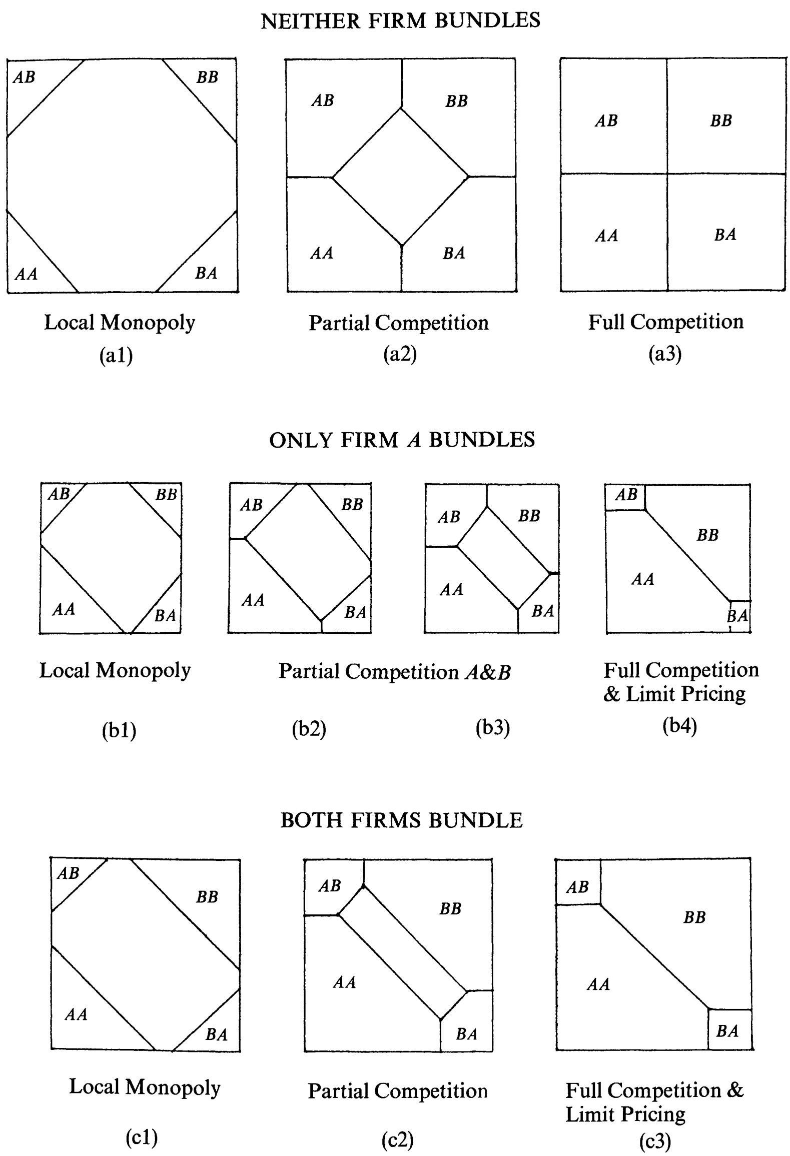

Figure 2

Since we found that "compatibility" was a (strictly) dominant strategy for both firms, it follows that firms choosing compatible components also would prefer a pure component strategy to a pure bundling strategy.[5] Thus we can state:

Lemma 1. If the two firms sell compatible components, the "pure bundling" strategy is dominated by the "pure components" strategy. If the two firms sell incompatible components, then the three marketing strategies are equivalent to pure bundling.

Proof. See the argument above and Matutes and Regibeau [1988].

From Lemma 1, it follows that a complete discussion of the second stage of the game only requires a discussion of the choice between mixed bundling and pure component strategies when firms have chosen compatibility. Before discussing that choice, it is useful to briefly restate the intuition behind the first part of the lemma.

First, as shown in Figure 2, the configuration of the market and thus the nature of the competition between the two firms depends on the level of the reservation price, C.[6] For low values of C (graphs (a1), (b1), (c1)), the firms do not find it profitable to serve the whole market. Indeed, for very low C, the areas served by each of the systems available do not touch. We refer to this as the case of "local monopoly", since systems do not compete for customers. As C increases (graphs (a2), (b2), (b3), (c2)), each pure system starts competing with the "hybrid" systems ("partial competition"). For still higher values of C (graphs (a3), (b4), (c3)), the whole market is served and all systems compete directly with each other ("full competition"). The first two rows of Figure 2 illustrate these three cases when at least one firm chooses a "pure component" strategy. When one or more firms choose a "mixed bundling" strategy, there is also a range of values of C for which the areas served by the two pure systems touch without triggering active competition for the consumers who are at the market boundary (i.e. the firms "limit price").[7]

Lemma 1 is the result of two effects. First, compatibility increases the number of systems that can be assembled from two (i.e. AA and BB) to four (i.e. AA, AB, BA, BB). This enables some consumers to obtain a system that is closer to their ideal specification. At any prices for which the market is not

[5] This equivalence results from our assumption that consumers do not derive any utility from consuming a single good. If consumers could increase their utility by consuming a single good, some of them could choose to purchase a single component under "incompatibility" but they would still be restricted to purchasing the whole system under "pure bundling".

[6] More precisely, it depends on the value of C relative to the extent of product differentiation between the two firms. This can be seen by defining the surplus derived by a consumer located at (d_{1i}, d_{2j}) as $C-\lambda(d_{1i}+d_{2j})-P_{1i}-P_{2j}$. Since the results only depends on C/λ, we decided to set $\lambda=1$.

[7] This is the range of values for which each firm is at a kink on its residual demand curve. For a discussion of the same concept in other spatial models, see Gabszewicz and Thisse [1986].

fully served, this increase in variety shifts industry demand up since, *at these prices*, some consumers who were too dissatisfied with the pure systems to make any purchase now decide to acquire one of the mixed systems. However, at prices for which the market is fully served, the greater variety of systems available does not increase the number of units purchased because individual consumers have perfectly inelastic demands. It follows that the 'variety increasing effect' is most powerful when systems do not directly compete with each other (i.e. our "local monopoly" case) and disappears once the whole market is served.

The second effect relates to the firms' incentives to cut prices. When an incompatible firm lowers the price of one component, it attracts additional consumers who will buy both components from the firm; cutting the price of one component increases equally the demand for both components in the system (i.e. the firm fully "internalizes" the complementarity link between the two components). In a compatible world a decrease in the price of firm A's first component increases the demand for its pure system, AA, as well as for the mixed system AB. The greater demand for AB does not of course increase the demand for A's second component. Furthermore, when the whole market is served, a higher demand for AA does not raise the demand for A's second component either because AA gains market share exclusively at the expense of the mixed system BA which also includes A's second component. If the market is not completely served, the higher demand for AA does create a greater demand for A's second component, but it is only a fraction of the increase in the demand for firm A's first component. It follows that firm A's price cutting incentives are lower with compatibility than with incompatibility and that this difference is greater if the market is more completely served.[8]

The consequences of this second effect on profits depend on the configuration of the market. If systems are local monopolies, a firm that chooses a pure bundling strategy fully internalizes the complementarity effects. This can only increase profits since it does not trigger any adverse price reaction from the other firm. If the firms' pure systems compete directly for market share, however, "full internalization" drives down equilibrium prices excessively and decreases equilibrium profits.

The choice between "mixed bundling" and a "pure component" strategy is not as clear-cut. With "mixed bundling", a firm can take advantage of the increase in system variety *and* price their own system to internalize fully the complementarity effects. When each system has a local monopoly (see Figure 2), one might expect that "mixed bundling" is an ideal strategy since both the "variety increasing" and "complementarity" effects tend to increase profits. However, Proposition 1 shows that this intuition is not correct.

[8] In other words, the residual demand faced by each firm is less elastic under compatibility than under incompatibility.

Proposition 1. Define π^{kl} as a firm's profit when compatibility prevails and the firm chooses marketing strategy k and its rival chooses strategy l, with $k, l \in \{M, N\}$ where M stands for "mixed bundling" and N for "pure component". The payoffs and perfect Nash equilibria of the two-stage subgame starting at the point where firms have decided to supply compatible components are as follows:

$$\text{—for} \quad C < 2.39, \quad \pi^{MN} > \pi^{NN} > \pi^{MM} > \pi^{NM}.$$

Both firms choose "mixed bundling", although they would both be better off if they could agree to adopt "pure component" strategies. In other words, the game has the structure of a prisoner's dilemma.

$$\text{—for} \quad 2.39 < C < 2.61, \quad \pi^{MN} > \pi^{NN} > \pi^{NM} > \pi^{MM}.$$

One firm chooses a "mixed bundling" strategy while the other chooses a "pure component" strategy.

$$\text{—for} \quad C > 2.61, \quad \pi^{NN} > \pi^{MN} > \pi^{NM} > \pi^{MM}.$$

Both firms select "pure component" strategies.

Proof. See appendix.[9] The rankings of equilibrium prices and social surpluses are given in Table I.

TABLE I
EQUILIBRIA OF THE TWO-STAGE SUBGAME WHEN COMPATIBILITY PREVAILS

$C < 2.39$	Firms choose "mixed bundling"	
	$\pi^{MN} > \pi^{NN} > \pi^{MM} > \pi^{NM}$	
	$P_M^{MN} >= P_M^{MM}$	Prisoner's Dilemma
	$SS^{NN} > SS^{MM} > SS^{MM}$	
$2.39 < C < 2.61$	One firm chooses "mixed bundling" the other firm chooses "pure component"	
	$\pi^{MN} > \pi^{NN} > \pi^{NM} > \pi^{MM}$	
	$P_M^{MN} > P_M^{MM}$	
	$SS^{NN} > SS^{MN} > SS^{MM}$	
$C > 2.61$	Both firms choose "pure component"	
	$\pi^{NN} > \pi^{MN} > \pi^{NM} > \pi^{MM}$	
	$P_M^{MN} > P_M^{MN}$	
	$SS^{NN} > SS^{MN} > SS^{MM}$	

For $k, l = N, M$.
P_M^{kl} is the price of the bundle when A chooses k and B chooses l.
π^{kl} is the profit earned by a firm choosing strategy k when the rival chooses strategy l.
SS^{kl} is total surplus when one firm chooses strategy k, and the rival strategy l.
P^{kl} is the price of a component set by a firm choosing strategy k when its rival chooses strategy l; for all values of C, $P^{MN} > P^{MM} > P^{NN} > P^{NM}$.

[9] While some cases can be solved analytically, in others simulations have been used to solve for the equilibrium values of prices and profits. The results of these simulations can be found in Matutes and Regibeau [1990].

While mixed bundling enables the firm to internalize fully the complementarity effects for its pure system, it also negates its incentives to internalize the complementarity effects for the hybrid systems. More precisely, given its rival's prices, a firm that has decided to bundle will set a lower price for its pure system and a higher price for its separate components than a firm that has chosen a pure component strategy. It follows that the firm that chooses a mixed bundling strategy lowers the residual demand for the hybrid systems left to its non-bundling rival, and if firms are local monopolies, keeps the demand for its own system unchanged. This leads the non-bundling rival to lower the price of its individual components.[10] In other words, the bundling firm gets a "free ride" from its rival, whose lower priced components help promote the sale of the hybrid systems. It follows that the bundling firm's residual demand tends to shift upwards while the non-bundling firm's residual demand tends to shift downward, yielding $\pi^{MN} > \pi^{NN}$ and $\pi^{NM} < \pi^{NN}$. A similar intuition explains why $\pi^{MM} > \pi^{NM}$ and $\pi^{MN} > \pi^{MM}$. When comparing the MM equilibrium to the NN equilibrium, one sees that the increased opportunity for internalizing complementary links on the firms' own system without having to change the prices that they set for their individual components increases the firms' profits from pure systems but decreases their profits from hybrids. This second effect dominates so that $\pi^{NN} > \pi^{MM}$ and we have a prisoner's dilemma.[11]

If the firms are full competitors regardless of their bundling choices, there is an additional effect that helps reduce the firms' unilateral incentives to choose a "mixed bundling" strategy. Again, given its rival's prices, the bundling firm will set a lower price for its system and a higher price for its components than a firm that has chosen a pure component strategy. However, this triggers a more severe price cut by the rival than in the case of local monopoly because the lower price of the bundle has also taken market share away from the

[10] The non-bundling firm's maximization problem is:

$$\max_{P_{1B},P_{2B}} (P_{1B}+P_{2B})D(P_{1B}+P_{2B})+P_{1B}D(P_{1B}+P_{2A})+P_{2B}D(P_{1A}+P_{2B})$$

where $D(P_{1i}+P_{2j})$ is the "monopoly" demand for the system made of components $1i$ and $2j$. Using the first order conditions and assuming that the second order conditions hold everywhere one gets:

$$\text{sign of }(dP_{1B}/dP_{2A}) = \text{sign of }[D'(P_{1B}+P_{2A})+P_{1B}D''(P_{1B}+P_{2A})]$$

Sufficient conditions for this derivative to be negative are that D be downward sloping and non-convex in the price of the system. With our specification of demand, however, D is convex in the price of the system. Still, the derivative has a negative sign in all configurations. Similar conditions can easily be obtained for the case where the two components are not perfect complements.

[11] As discussed briefly in section V, $\pi^{NN} > \pi^{MM}$ still holds if the uniform distribution of consumers is modified to give relatively less weight to the demand for hybrid systems. Still, other distributions might reverse the sign of the inequality. While this would not affect the equilibrium strategies of the firms, the game would no longer be a prisoners' dilemma for low values of C.

rival's pure system.[12] Moreover, as the two firms' pure systems are now in direct competition with each other, this aggressive price reaction actually decreases the residual demand that the bundling firm faces for its own system. The relative importance of this effect increases with the level of consumers' reservation price, C, yielding $\pi^{NN} > \pi^{NM}$ for $C > 2.39$ and $\pi^{MN} < \pi^{NN}$ for $C > 2.61$.

Finally, for intermediate values of C, the firms' choice of marketing strategy also affects the configuration of the market. Since mixed bundling leads the firm to price its own system more aggressively, it may induce a change in market structure from partial competition to limit pricing or to full competition. This intensifies price competition, reducing the firms' incentives to mix-bundle. Indeed π^{NM} becomes larger than π^{MM} as soon as the market structure changes from limit pricing to full competition when both firms bundle. Similarly, for higher values of C, mixed bundling by either firm changes the market configuration from partial competition to full competition, and one firm at most mix-bundles.

IV. WELFARE ANALYSIS AND COMPATIBILITY CHOICE

The introduction of mixed bundling strategies affects welfare, measured as the sum of consumer surplus and profits, in two ways. First, if both firms have chosen to offer compatible components, mixed bundling tends to reduce social surplus. Indeed, a situation where both firms bundle is never socially optimal. Moreover, having one firm bundle is desirable only for a very narrow range of reservation prices which does not overlap with the range for which it is an equilibrium outcome of the subgame.

Since individual demands are inelastic, price just represents a transfer from consumers to firms so that the ranking of social surplus depends only on the total area served in the different equilibria and on the total distance "travelled" by the consumers who are served. When systems are local monopolies (i.e. for low values of C), both effects tend to make social surplus larger when firms do not bundle than in the mixed bundling equilibrium. For any total area served, the total distance travelled is minimized if each system serves a market area of equal size. Since the price of the bundles (i.e. the pure systems) is lower than the prices of the hybrids, the mixed bundling equilibrium involves higher travel costs than an equilibrium without bundling that serves the same total market area. Moreover, the market area served without bundling is higher than when mixed bundling prevails, since the increased market of the pure systems under mixed bundling does not make up for the decrease in the size of the markets for hybrids. As systems begin to compete with each other, the total area served becomes larger in the

[12] In other words the firm's reaction functions are upward sloping with respect to the price of their rival's pure system.

mixed bundling equilibrium than without bundling so that the two effects work in opposite directions. Still, the mixed bundling equilibrium is always socially inferior to a situation without bundling.[13] This is especially clear when the whole market is served under all regimes since mixed bundling distorts the equilibrium market areas away from a symmetric configuration without increasing the market area served.

Mixed bundling strategies also affect welfare by changing the range of parameters over which the firms choose to supply compatible components. As we have seen, for $C < 2.39$ both firms choose mixed bundling whenever compatibility prevails. This has two opposing effects on welfare. On the one hand, as discussed in section III, mixed bundling reduces the profit of each firm. This makes compatibility relatively less attractive for both firms. On the other hand, mixed bundling also decreases social welfare. This makes a compatibility equilibrium relatively less attractive socially. It can be shown that the net effect is an increase in the area where excessive standardization occurs.

For $2.39 < C < 2.61$, compatibility will arise as long as $\pi^{MN} > \alpha_A + \pi_I$, where α_A is the cost of achieving compatibility unilaterally by building an adaptor and π_I is the profit of each firm if incompatibility prevails. In the absence of bundling, compatibility would arise if $\pi^{NN} > \alpha_A + \pi_I$. As $\pi^{MN} > \pi^{NN}$, compatibility will occur for a wider range of α_A with mixed bundling. Since mixed bundling also decreases social surplus, the range of parameters for which excessive standardization occurs must be larger than if mixed bundling was not an option. Finally, the analysis of Matutes and Regibeau [1988] is unchanged for $C > 2.61$ since neither firm decides to use mixed bundling in equilibrium.

V. DISCUSSION

Some of our assumptions about the demand side of the model can be relaxed without affecting the nature of our results. While the complementarity between the two components is essential to our story, the components need not be consumed in fixed proportions. All that matters is that the complementarity link be "strong enough".[14] Another peculiar aspect of our model is that the uniform distribution of consumers over the unit square implicitly assumes that there is no "brand preference", i.e. that consumers

[13] For a narrow range of values ($1.8 < C < 2.11$), the socially optimal outcome is for only one firm to bundle. Still, even over that range, the equilibrium is MM and is socially inferior to NN. Further, MN is socially inferior to NN over the range of values for which MN is the market equilibrium. It is thus possible to say that the firms exhibit a socially excessive propensity to bundle.

[14] In the sense that the condition in note 10, or rather its equivalent for imperfect (essential) complements:

$$D_2'(P_{iB}, P_{iA}) + P_{iB} D_{12}''(P_{iB}, P_{iA}) < 0$$

is satisfied.

who prefer firm A's specification of the first component do not tend to prefer firm A's version of the second component. To capture the possibility of brand preferences, we assigned a weight of $0 < t < 1$ to the demand for hybrids and recomputed all prices, profits, and social surpluses for several values of t. This did not modify our qualitative results. While one would not expect a decrease in the relative weight given to the hybrid systems to effect the firms' unilateral incentives to bundle, it might conceivably affect the ranking of π^{NN} and π^{MM}, which depends on whether the decrease in profits from hybrids outweighs the gains on the pure systems sold by the bundling firms. This is not the case, however, because a low weight on the demand for mixed systems has two opposing effects. On the one hand it decreases the importance of the losses incurred on the hybrids. This tends to make MM more attractive to the firms. On the other hand, a low value of t limits the effect of mixed systems on the pricing decisions of non-bundling firms. This decreases the difference between the degree of "internalization" of complementarity effects in NN and MM, limiting the extra profits that bundling firms can make on their pure systems.

There is an abundant literature on the incentives for a monopolist to choose a bundling or mixed bundling strategy (e.g. Adams and Yellen [1976] and Schmalensee [1982, 1984]). Typically, a monopolist sells each of two goods. By offering the goods as a bundle (while possibly still selling the individual products independently), the firm can discriminate between consumers. In such a context, mixed bundling is always a weakly dominant strategy since it includes the other two options as special cases. This conclusion does not extend to our model of duopoly. While mixed bundling would still be a (strictly) dominant strategy if the two rival components were offered at constant marginal cost by a competitive industry (i.e. for given prices of the rival components), we have shown that this need not be the case when the firm takes into account the effect of its bundling decision on the equilibrium prices (since it is possible to have $\pi^{NN} > \pi^{MN}$ and/or $\pi^{NM} > \pi^{MM}$). We also showed that, when mixed bundling is indeed a dominant strategy for both firms, this results in a prisoner's dilemma.

These conclusions are somewhat sensitive to the timing of the game. As we have argued earlier, modelling the bundling and pricing choices as different stages of the game only makes sense if the bundling is less easily reversible than the pricing decision. This seems to be a reasonable assumption whenever bundling involves some changes in the products' design or packaging. Examples of such situations include 'all in one' stereo centers, cameras with built-in lenses, computers with attached monitors or factory-installed option packages in the car industry. In other cases, however, consumers are granted a discount simply because they purchase a complete set of independently available components that have not been redesigned or repackaged. It is for example usually possible to obtain a discount on the purchase of full computer or stereo systems even if their components have not been physically tied together. In such instances, the decision to offer a discount on "bundles" is better specified as part of the firm's pricing decision and the last two stages of our game should be collapsed into one. In such a two-stage game, one can show that, whenever compatibility prevails in the first stage, mixed bundling is a dominant strategy for each firm.[15] Moreover, this pricing/marketing subgame has the structure of a prisoner's dilemma for all values of C and social surplus is always strictly lower than without mixed bundling. Since mixed bundling occurs for all Cs, it also affects the compatibility decisions of the firms for all values of C. Compared to the three-stage game, the region of 'excess standardization' is enlarged for $C > 2.61$ as well.

Our conclusions with respect to pricing incentives are consistent with Anderson and Leruth [1991]. They use a model where consumers' tastes are random and assume a compatible world. They focus on the case where all consumers are served and conclude that firms will offer the system at a discount price only if they cannot commit to a marketing strategy before choosing the level of prices.

Our results cannot be directly compared to the literature on strategic tie-ins (e.g. Whinston [1990], Seidman [1989]) since neither of our firms has a monopoly on either of the two goods. Still, it is interesting to notice that, as in Whinston [1990], bundling[16] can be an exclusionary device. In an entry game where the incumbent can commit to a bundling decision before entry occurs, bundling by the incumbent discourages entry when $\max[\pi^{MM}, \pi^{NM}] < F < \max[\pi^{NN}, \pi^{MN}]$, where F is the entry fee.

VI. CONCLUSION

This paper has presented a simple model of compatibility and bundling in industries where consumers assemble several necessary components into a

[15] A sketch of the proof is as follows. As in the three stage game, we only have to discuss the subgame where compatibility prevails. Let us start by observing that in the three stage game a firm was given the opportunity to offer discounts on whole systems in the pricing stage only if it had chosen a mixed bundling strategy in the second stage. In the two stage game, the firm's ability to offer discounts is not constrained by any previous choice of 'marketing strategy'. Therefore, we can say that whenever both firms chose mixed bundling in the three-stage game, they will also choose to offer discounts in the two-stage game and the equilibrium prices will be the same. On the other hand, it is possible that the firms will also choose to offer discounts for values of C where at least one firm decided in favor of a pure component strategy in the three-stage game. To explore this, one must first determine the sign of $\partial\pi^{MN}/\partial P_M$ evaluated at the prices that prevail in the NN equilibrium. This derivative is negative, establishing a firm's unilateral incentive to offer a discount if its rival does not. One can show too that $\partial\pi^{MM}/\partial P_M$ is also negative at the prices prevailing in the BN equilibrium, establishing that a firm will not want to be the only one not offering a discount. It follows that, given the opportunity, both firms will choose to offer a discount on their own system.

These results are quite similar to the one obtained by McAfee, McMillan and Whinston [1989]. Indeed, the general line of our argument follows the proof of their proposition 1. The only significant difference is that, in our model, consumers do not derive any satisfaction from consuming only one of the two goods.

[16] While we refer to mixed bundling, the tie-in commitment in Whinston [1990] is better interpreted as pure bundling.

system that is close to their ideal. It has been shown that the availability of mixed bundling strategies tends to increase the range of parameters for which socially excessive standardization occurs. Besides enriching the recent analyses of compatibility decisions in multi-component industries, our model fills a gap in the bundling literature by extending the basic framework of monopoly bundling to a duopoly setting. Such an extension substantially modifies the conclusion that would obtain for a monopolist. While the opportunity to choose mixed bundling could not hurt a monopolist, it can decrease the equilibrium profits of a duopolist. It follows that mixed bundling can also be used by an incumbent firm to exclude a potential entrant from the industry.

Another implication of this paper is that the firm's ability to exploit the demand shift (or endogenous 'network externality') associated with compatibility depends crucially on the range and timing of marketing strategies available to the firms.

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APPENDIX

The derivations for the non-bundling case can be found in Matutes and Regibeau [1988]. This appendix only provides the first order conditions used to obtain the equilibrium prices when either one or both firms bundle. The firms' maximization problems, the expressions for profits and consumer surpluses and the results of the simulations can be found in our working paper (Matutes and Regibeau [1990]).

Define P_{Mj}, $j = A, B$ as the price that firm i sets for its full system and P_{ij}, $i = 1, 2$, $j = A, B$, as the price of the individual component i set by firm j.

I. Both Firms Bundle

Each firm sells the two components independently and offer a system at a discount.

(i) *Local Monopoly*

The equilibrium prices are:

$$P_{Mj} = C/3 \quad P_{ij} = C/4 \quad i = 1,2 \quad j = A,B$$

These solutions apply as long as the market areas served by each system do not touch, i.e. as long as $C < 6/7$.

(ii) *Partial Competition*

The first order conditions are, after imposing symmetry:

(A1) $$(2P_{ij} - P_{mi} + 1)^2 - 2(1 - C + 2P_{ij})^2 + 2P_{MA}(P_{MA} - 1 - 2P_{ij}) + 2P_{ij}(2C - 1 - P_{MA} - 2P_{ij}) = 0$$

(A2) $$(P_{MA}(2C - 1 - P_{MA} - 2P_{ij}) + (P_{MA} + 1 - 2P_{ij})^2 - 2(P_{MA} - C + 1)^2 + P_{ij}(4P_{ij} - 2P_{MA} - 2) = 0$$

(A1) and (A2) provide valid solutions as long as the market is not completely served at equilibrium prices, i.e. if $C - 1 - P_{MA} < 0$, or $C < 1.8$.

(iii) *Adjacent Markets*

In this market configuration, the firms refrain from competing directly on their bundle (loosely speaking, they are at the kink of their respective residual demand curves), setting their prices so that their market areas just touch. This yields:

$$P_{Mj} = C - 1 \quad j = A,B$$

Given this limit price behavior, both firms still have to determine the price of their individual components. The condition is:

(A3) $$(2P_{ij} - C)(4P_{ij} + 1 - 2C) = 0$$

where $P_{ij} = (C/2) - 0.25$ is the root that satisfies the second order conditions. These expressions are valid as long as "limit pricing" is each firm's best response to its rival's behavior, i.e. as long as $C < 7/3$.

(iv) *Full Competition*

The first order conditions are:

(A4) $$(1 + 2P_{ij} - P_{Mj})^2 - 2(2P_{ij} - P_{Mj})^2 - 2P_{Mj} + 2P_{ij}(1 + P_{Mj} - 2P_{ij}) = 0$$

(A5) $$(P_{Mj} + 1 - 2P_{ij})(1 + 2P_{Mj} - 4P_{ij}) = 0$$

The solution to (A4) and (A5) that satisfies the second order conditions is:

$$P_{Mj} = 4/3, \quad P_{ij} = 11/12 \quad i = 1,2 \quad j = A,B$$

These solutions prevail as long as the whole market is served at the equilibrium prices, i.e. as long as $C - 1 - (4/3) > 0$ or $C > 7/3$.

II. Only Firm A Bundles

Both firms sell the two components independently and firm A also offers its system at a discount.

(i) *Local Monopoly*

The first order conditions and using symmetry, we get:

$$(C-P_{iA}-P_{iB})(C-P_{iA}-3P_{iB})+(C-2P_{iB})(C-6P_{iB})=0 \tag{A6}$$

Using (A6) and the FOCs for A yields:

$$P_{iA}=[26+(56)^{1/2}]C/124 \quad \text{and} \quad P_{iB}=[46-3(56)^{1/2}]C/124$$

This solution holds as long as both firms remain "local monopolists" at the equilibrium prices. As $P_{MA}<2P_{iB}$, the market for firm A's pure system touches the markets for the hybrid systems first, so that the solution we have obtained applies as long as $2C/3<1-0.5400534C$ or $C<0.82869$.

(ii) *Partial Competition (1)*

The following first order conditions apply to the case where the area served by firm A's pure system has a common boundary with the areas served by the hybrids, while the market served by B's own system does not.

$$(1+P_{iB}+P_{iA}-P_{MA})-2(1-C+P_{iA}+P_{iB})^2+2P_{MA}(P_{MA}-1-P_{iA}-P_{iB})+ \\ 2P_{iA}(2C-P_{iA}-P_{iB}-P_{MA}-1)=0 \tag{A7}$$

$$P_{MA}(2C-1-P_{MA}-P_{iA}-P_{iB}) \\ +(1/2)(1+P_{MA}-P_{iA}-P_{iB})(4C-3P_{iA}-3P_{iB}-P_{MA}-1) \\ +P_{iA}(3P_iA+3P_{iB}-1-P_{MA}-2C)=0 \tag{A8}$$

$$4(C-2P_{iB})^2+(1+P_{MA}-P_{iA}-P_{iB})(4C-3P_{iB}-3P_{iA}-P_{MA}-1) \\ +P_{iB}38P_{iB}+6P_{iA}-2P_{MA}-2-20C)=0 \tag{A9}$$

The system of equations (A7) to (A9) can be solved by computer for several values of C. Based on the equilibrium prices obtained, it can be checked that this market configuration prevails for $0.829<C<0.867$.

(iii) *Partial Competition (2)*

For $C>0.867$, the areas served by the hybrid systems touch the areas served by each of the pure systems. The first order conditions are:

$$(P_{iA}+P_{iB}-P_{MA}+1)^2-2(1-C+P_{iA}+P_{iB})^2+2P_{MA}(P_{MA}-1-P_{iB}-P_{iB}) \\ +2P_{iA}(2C-1-P_{MA}-P_{iA}-P_{iB})=0 \tag{A10}$$

$$(1+P_{MA}-P_{iA}-P_{iB})(1+P_{iB}-P_{iA})-0.5(2+P_{MA}+2P_{iB}-2C)^2 \\ +P_A(2C-1-P_{MA}-P_{iB}-P_{iA})+P_{iA}(2P_{iA}-P_{MA}-2)=0 \tag{A11}$$

$$(1+P_{iA}-P_{iB})^2-2(1-C+P_{iA}+P_{iB})^2+(1+P_{MA}-P_{iB}-P_{iA})(1+P_{iB}-P_{iA}) \\ -0.5(2-2C+2P_{iB}+P_{MA})^2+P_{iB}(8C-10-8P_{iB}-6P_{iA}-PM_A)=0 \tag{A12}$$

The system of equations (A10) to (A12) can be solved by computer for different values of C. Based on the equilibrium prices obtained, this market configuration prevails for $0.867<C<2$.

(iv) *Adjacent Markets*

For a range beyond $C=2$, both firms set prices for their complete systems so as to leave consumers located at the common market boundary with exactly zero surplus.

This yields:

(A13) $P_{MA} = C-1$

(A14) $P_{iB} = (C-1)/2$

However, there is no such "limit pricing" on firm A's individual components. The corresponding first order condition is:

(A15) $3P_{iA}^2 - P_{iA}(1+3C) + (3C^2-1)/4 + C/2 = 0$

where $P_{iA} = (3C-1)/6$ is the root that satisfies the second order conditions. This market configuration prevails as long as the whole market is served at equilibrium prices and as long as "limit pricing" is each firm's best response to the prices of its rival, i.e. as long as $2 < C < 2.5$.

(v) *Full Competition*

The first order conditions are:

(A16) $$(1+P_{iA}+P_{iB}-P_{MA})^2 - 0.5(2P_{iA}-P_{MA})^2 + P_{MA}(P_{MA}-2P_{iB}-2) + 2P_{iA}(1+P_{iB}-P_{iA}) = 0$$

(A17) $$(1+P_{iB}-P_{iA})(1+2P_{MA}-P_{iA}-P_{iB}) + P_{iA}(2P_{iA}-P_{MA}-2) = 0$$

(A18) $$(1+P_{iA}-P_{iB})^2 + (1+P_{iB}-P_{iA})(1+P_{MA}-P_{iA}-P_{iB}) - 0.5(2P_{iA}-P_{MA})^2 + P_{iB}(P_{MA}-2P_{iA}-2) = 0$$

The system of equations (A16) to (A18) is independent of C and can be solved by computer, yielding

$$P_{MA} = 1.5, \quad P_{iA} = 1.08333, \quad P_{iB} = 0.75, \quad \pi_A = 0.824074 \quad \textit{and} \quad \pi_B = 0.75$$

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