“Mix and match”: product compatibility without network externalities

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and

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In industries where consumers can assemble their own systems, firms must decide whether to make their components compatible with those of their rivals. We examine a two-stage game in which two fully integrated firms make their compatibility decisions before competing in prices. The symmetric perfect Nash equilibrium of this game is shown to involve full compatibility. Although compatibility leads to higher prices than incompatibility, it also increases the variety of systems available so that some consumers are better off with compatibility, while others are hurt. If standardization is costless, compatibility increases social surplus, but may decrease consumer surplus.

1. Introduction

Many multiproduct firms sell systems—lines of products where each good cannot, or usually is not, used separately but might still be purchased separately. Examples are photography, where the typical product line includes cameras, lenses, film and film processing services, and computers, where a system involves software and several hardware components.

In some industries every component of a system produced by a firm can be used with every component manufactured by any other firm. This is the case for the home stereo industry where, for example, a Sanyo tape deck can be combined with a Pioneer receiver and Kenwood speakers. Such industries will be referred to as fully compatible.

In other instances the systems produced by different firms are not compatible at all. A leading example is the home video industry, where VHS video recorders cannot play cassettes recorded using the Beta format.¹

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¹ An industry can also be partially compatible. This was the case in the razor industry when some manufacturers’ blades could be used in their rivals’ razors while their own razors were not compatible with their rivals’ blades. For an analysis of this case, see Matutes and Regibeau (1987).
To the extent that compatibility, or the absence thereof, results from conscious decisions by manufacturers, the firms' incentives to produce compatible products and the social optimality of such incentives must be examined.

In the by now standard framework first explored by Katz and Shapiro (1985) and Farrell and Saloner (1985), a system of compatible components is treated as a single good characterized by positive consumption externalities. Such network externalities arise because the utility a consumer obtains from a system increases with the number of others using compatible products. This is so since, for example, the larger is the network of compatible goods, the better are the possibilities of exchange, the quality of after-sale services, and the information available.

With network externalities the firms' incentives to produce compatible systems and the social optimality of these private incentives have been shown to depend on the firms' relative size and on how compatibility can be enforced. If compatibility can only be achieved with the agreement of all firms (adoption of a common standard),2 privately profitable industrywide standards are socially desirable, but some socially desirable standardization will be rejected. If, on the other hand, standardization can be enforced unilaterally (by building an adaptor) and firms differ greatly in sizes, private incentives to standardize may be excessive.

These welfare results are criticized by Farrell and Saloner (1986a), who argue that standardization has an additional social cost since it reduces product variety. They show that if the tradeoff between network externalities and product variety is explicitly considered, the firms' incentives to produce compatible products can be socially excessive.

Although Katz and Shapiro (1985) and Farrell and Saloner (1985) recognize that issues of standardization mostly arise in industries producing systems, they model the firms as selling a single good. This implicitly assumes either that every firm sells every component of a system, a single good, or that firms each sell one similar component (e.g., software) to consumers who have already bought the rest of the system (e.g., the personal computer).

The purpose of this article is to show that additional insights about these issues can be gained by explicitly modeling a system as a set of components instead of treating it as a single good. We consider industries where each firm sells every component of a complete system, but where it may be possible to use a system that combines components produced by different manufacturers.

We show that, contrary to Farrell and Saloner's (1986a) argument, product compatibility might indeed increase the range of consumers' choices. If compatibility prevails, consumers can assemble their own systems by buying components from different firms. If, on the other hand, the components manufactured by different firms are not compatible, buyers can purchase a full system only from a single supplier. The number of different systems available to consumers is thus greater when firms produce compatible components. It follows that compatibility enables some consumers to obtain a system whose features are closer to their ideal.

We also show that, even in the absence of network externalities, there are incentives for firms to produce compatible systems. Indeed, in a game where firms decide whether to make their system compatible before competing in prices, we show that compatibility is the unique outcome of symmetric perfect Nash equilibria, whenever standardization can be enforced unilaterally. This is the result of two effects. First, compatibility enables consumers to build a system that is closer to their ideal. This shifts the industry demand curve upwards and makes the market more profitable. Second, compatibility weakens each firm's incentives to cut prices. When firms sell incompatible components, a decrease in one firm's price

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2 See Farrell and Saloner (1988) for an analysis of the choice of a common standard by voluntary standard committees.
increases its sales at the expense of its rivals. With compatibility, however, cutting the price of one good will increase the sales of all systems using that component, including systems that involve components produced by other firms. Since some of the benefits of the price cut will be appropriated by other firms, each firm will behave less aggressively than in the case of incompatibility.

Finally, we show that a move to compatibility unambiguously decreases the welfare of some consumers, while it makes other consumers better off. We show that consumer surplus and social surplus (gross of standardization costs) are generally higher when full compatibility prevails. If standardization costs are introduced, however, compatibility can arise as the equilibrium outcome of the game, even though it is socially inferior to incompatibility.

We present the basic model in Section 2. The symmetric equilibrium prices and profits under compatibility and incompatibility are determined in Section 3. Section 4 presents the equilibria of the game, and Section 5 examines the welfare implications of compatibility. We examine the robustness of our analysis in Section 6, and briefly summarize the results, discuss their applicability, and suggest a few areas for future research in Section 7.

2. The model

Both firms produce the two components of a system and maximize their own profits. Each component is produced at constant marginal cost, and there are no economies of scope. Without loss of generality, the marginal costs are all set equal to zero. If the components sold by the two firms are not compatible, only two systems are available for consumers to purchase: firm A’s system, \( X_{AA} \), which combines \( X_{1A} \) and \( X_{2A} \) and firm B’s system, \( X_{BB} \). If the components are compatible, consumers have the additional options of \( X_{BA} \) and \( X_{AB} \).

We solve the following two-stage game for its symmetric perfect Nash equilibrium. In the first stage the firms simultaneously decide whether to make their components compatible with their rival’s. In the second stage, the firms compete in prices while taking the other firm’s prices as given—the firms behave as Bertrand competitors.

We consider two situations. In the first case compatibility can be achieved unilaterally—it can be enforced by any one firm. This occurs whenever a firm can make its components compatible with its rival’s by building an adaptor. The cost of building such an adaptor is \( \alpha_A \). In the second case compatibility can only prevail if both firms agree to it. Such a situation can, for example, arise if each firm has a choice between a “common knowledge” technology accessible to both firms and a technology that is inaccessible to its rival or cannot profitably be used by him. In this setting compatibility can only be achieved if both firms choose the common-knowledge technology. The cost to a firm of adopting this common standard is defined as \( \alpha_c \).

□ Consumers. Consumers are uniformly distributed on the unit square (see Figure 1), where firm A is located at the origin, while firm B is located at the point of coordinates \((1, 1)\). A consumer located at a point of coordinates \((g_1, g_2)\) has a preferred first component that is \(g_1\) away from firm A’s first component and a preferred second component that is \(g_2\) away from firm A’s second component. Similarly, the distances between the consumer’s preferred point and firm B’s components are \(1 - g_1\) and \(1 - g_2\). As a matter of convenience, we assume that every consumer purchases the two components in the fixed proportion of one unit of good 1 to each unit of good 2.\(^4\)

\(^3\) The location of the firm is exogenous. We discuss the significance of this assumption in the Conclusion.

\(^4\) Allowing for fixed proportions other than one-to-one does not change the nature of the results (Matutes and Regibeau, 1987). Similarly, the qualitative results are preserved as long as the two components are sufficiently strong complements.
A consumer buying one unit of system $X_{ij}$ has a surplus of
\[ C - \lambda (d_{1i} + d_{2j}) - P_{ij}, \quad i, j = A, B, \]
where $C$ is the reservation price common to all consumers, $d_{ij}$ is the distance between the consumer's preferred specification of the $i$th component and the specification of the $i$th component sold by firm $j$, $P_{ij}$ is the price of the system $X_{ij}$, and $\lambda > 0$ measures the degree of horizontal product differentiation between the two firms' products. Each consumer buys one unit of her preferred system, provided that this leaves her with a nonnegative surplus.

3. Equilibrium prices and profits

Figure 2 shows the division of the market between the systems available when the components of different firms are fully compatible and when firms sell incompatible components. There are several cases, depending on the level of the reservation price $C$ relative to the product differentiation parameter $\lambda$. The equilibrium values corresponding to these cases are presented in Table 1, where $P^*$ represents the equilibrium price of a system, $\Pi^*$ is the profit of each firm, $CS^*$ is the consumer surplus, and $SS^*$ stands for social surplus.

Let us consider the case where the two firms sell incompatible components. We assume first that the whole market is served. A consumer located at $(g_1, g_2)$ will purchase the system from firm $A$ rather than from firm $B$ if $P_A + \lambda (g_1 + g_2) \leq P_B + \lambda (2 - g_1 - g_2)$, i.e., if she is located below the line $g_2 = [(P_B - P_A)/2\lambda] + 1 - g_1$, where $P_i$ represents the price of firm $i$'s system.\(^5\)

For $P_A \geq P_B$ the firms' profits are:
\[
\Pi_A = (P_A/2)[1 + (P_B - P_A)/2\lambda]^2 \\
\Pi_B = P_B[1 - (1/2)(1 + (P_B - P_A)/2\lambda)^2].
\]

Maximizing profits with respect to $P_A$ and $P_B$, respectively, and imposing symmetry in either of the first-order conditions yield $P^*_i = \lambda$, and thus $\Pi_i = \lambda/2$. This is a valid solution as long as the whole market is indeed served at equilibrium prices, i.e., as long as $C - P^*_i - \lambda \geq 0$, or $C \geq 2\lambda$. Consumer surplus is
\[
CS = 2 \int_0^1 \int_0^{1-g_1} [C - \lambda (g_1 + g_2) - P^*] dg_2 dg_1 = C - 5\lambda/3.
\]

If $C < 2\lambda$, the whole market is not served at the equilibrium prices just derived. There are two cases. For low reservation prices the firms will behave as local monopolists, with firm $A$ serving all the consumers such that $C - \lambda (g_1 + g_2) - P_A \geq 0$. Maximizing

\(^5\)The same results obtain if each firm sets the prices of each component instead of the price of its complete system.
\[ \Pi_A = \left( \frac{P_A}{2} \right) \left[ \frac{(C - P_A)}{\lambda} \right]^2 \]

with respect to \( P_A \) yields \( P_A^* = C/3 \) and \( \Pi_A^* = 2C^2/(27\lambda^2) \). This is a valid solution if the firms’ markets do not overlap at the equilibrium prices, i.e. if \( C - \lambda - C/3 < 0 \), or \( C < 3\lambda/2 \).

For \( 3\lambda/2 < C < 2\lambda \), the firms engage in limit pricing in the sense that each firm sets its price so that its market just touches the other firm’s market (i.e., consumer surplus is zero on the market boundary). This implies that \( P_A = 2C - 2\lambda - P_B \) and \( P_B = 2C - 2\lambda - P_A \) so that \( P_A^* = C - \lambda \) and \( \Pi_A^* = (C - \lambda)/2 \).

The derivation of the results for the case where firms sell compatible components is in the Appendix. The possible market configurations are as follows.

For low reservation prices (i.e., \( C < 5\lambda \)) the two firms are local monopolists in both the compatibility and incompatibility equilibria, in the sense that the areas served by different systems do not touch. For higher reservation prices (i.e., \( 5\lambda \leq C \leq 7\lambda \)) the two firms are still local monopolists if they produce incompatible components, while there is some direct competition between systems if compatibility prevails. In both cases the market is not completely served.

For intermediate reservation prices (i.e., \( 7\lambda \leq C \leq 2\lambda \)) the configuration of the compatibility equilibrium is unchanged. Firms producing incompatible systems share the whole market but do not compete directly (i.e., they limit price). For \( C \) greater than \( 2\lambda \) the two firms are direct competitors under both regimes. With incompatibility the whole market is served, while some consumers choose not to buy any system in the compatibility equilibrium as long as \( C \) is smaller than \( 3\lambda \).

From Table 1 one can easily see that for all values of \( C \) and \( \lambda \) equilibrium prices and profits are higher when firms sell compatible components than when they sell incompatible ones. This is the result of two effects.
### TABLE I  Equilibrium Values for the Case of Two Integrated Firms

<table>
<thead>
<tr>
<th>Incompatibility</th>
<th>Compatibility</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Local Monopolists</td>
</tr>
<tr>
<td></td>
<td>$P_t^* = \frac{C}{3}$</td>
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<tr>
<td></td>
<td>$\Pi_t^* = \frac{2C^3}{27\lambda^3}$</td>
</tr>
<tr>
<td></td>
<td>$CS_t^* = \frac{8C^3}{81\lambda^3}$</td>
</tr>
<tr>
<td></td>
<td>$SS_t^* = \frac{20C^3}{81\lambda^3}$</td>
</tr>
</tbody>
</table>

$\phi < C < \frac{1}{6}\lambda$

$\frac{1}{6}\lambda < C < \frac{1}{3}\lambda$

$\frac{1}{3}\lambda < C < 2\lambda$

$2\lambda < C < 3\lambda$

$3\lambda < C$

<table>
<thead>
<tr>
<th>Adjacent Markets</th>
<th>Competitors: Partial Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_t^* = C - \lambda$</td>
<td>$P_t^* = \frac{P_t^<em>}{2} \left[ 1 - 2 \left( 1 + \frac{P_t^</em> - C}{\lambda} \right) \right]$</td>
</tr>
<tr>
<td>$\Pi_t^* = \frac{C - \lambda}{2}$</td>
<td>$\Pi_t^* = \frac{P_t^<em>}{2} \left[ 1 - 2 \left( 1 + \frac{P_t^</em> - C}{\lambda} \right) \right]$</td>
</tr>
<tr>
<td>$CS_t^* = \frac{\lambda}{3}$</td>
<td>$CS_t^* = \lambda \left[ 2C - \frac{2C^2}{\lambda} + \frac{8CP_t^<em>}{\lambda} - \frac{4P_t^</em>}{\lambda} - \frac{\alpha P_t^*}{\lambda} \right] - \lambda X^2$</td>
</tr>
<tr>
<td>$SS_t^* = C - \frac{2\lambda}{3}$</td>
<td>$SS_t^* = 2\Pi_t^* + CS_t^*$</td>
</tr>
</tbody>
</table>

$X = \frac{1}{\lambda} \left( C - 2P_t^* \right)^2 - 1$

<table>
<thead>
<tr>
<th>Direct Competitors</th>
<th>Direct Competitors: Full Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_t^* = \lambda$</td>
<td>$P_t^* = 2\lambda$</td>
</tr>
<tr>
<td>$\Pi_t^* = \frac{\lambda}{2}$</td>
<td>$\Pi_t^* = 1\lambda$</td>
</tr>
<tr>
<td>$CS_t^* = C - \frac{5\lambda}{3}$</td>
<td>$CS_t^* = C - \frac{5\lambda}{2}$</td>
</tr>
<tr>
<td>$SS_t^* = C - \frac{2\lambda}{3}$</td>
<td>$SS_t^* = \frac{C - \lambda}{2}$</td>
</tr>
<tr>
<td>$AS_t^* = 1$</td>
<td>$AS_t^* = 1$</td>
</tr>
<tr>
<td>$D_t^* = \gamma/3$</td>
<td>$D_t^* = \gamma/3$</td>
</tr>
</tbody>
</table>

First, compatibility makes it possible for consumers to combine components from different firms, thereby increasing the number of available systems from two to four. This is shown in Figure 2 where consumers can choose between systems located at each of the four corners instead of being limited to the complete systems sold by each firm. This implies that at any given price the number of consumers served is at least as large with compatibility as with incompatibility, since some consumers who would not purchase both components from any single firm are willing to assemble their own systems by mixing the two firms’ components. In other words, compatibility shifts industry demand upwards. When firms behave as local monopolists in both equilibria (i.e., for low $C$), this variety-increasing effect exactly doubles the area served at any given price. The strength of this demand shift decreases as the reservation price increases. The effect disappears as soon as the whole market is served under both compatibility and incompatibility.

Second, the firms have fewer incentives to cut prices when they produce compatible
components than when incompatibility prevails. In the incompatibility equilibrium a decrease in the price of firm A’s first component, for example, increases the demand for the firm’s whole system. With compatibility, however, a similar price cut increases the sales of all systems using the component, i.e., firm A’s complete system $X_{AA}$ and also system $X_{AB}$, which includes firm B’s second component. In other words, under incompatibility firm A captures the full benefits from its price cut, while with compatibility some of the benefits are obtained by its rival, so that firm A’s incentives to decrease prices are weaker in a compatible industry.

Figure 3 shows the areas captured by firm A for a given decrease in the price of its first component. The shaded areas show increases in the sales of this component, while the dotted areas represent increases in the sales of both of firm A’s components. The effect of compatibility on the firm’s price-cutting incentives is particularly clear when the whole market is served and systems compete directly with each other.

Without compatibility, firm A increases its market share for both components to the detriment of firm B when it reduces the price of its first component. With compatibility firm A only increases its market share for the first component. In the case where each system enjoys a local monopoly, a similar price cut increases the demand for firm A’s products more if components are compatible than if they are not. The equilibrium prices, however, will still be higher in the compatibility equilibrium because the increased demand is smaller relative to the area already served.\(^6\)

\[ q(P_i) \] as the demand for $X_{ij}$ when systems enjoy a local monopoly. With consumers uniformly distributed over the square, $q'(P_i) < 0$. With incompatibility the first-order condition for firm A is:

\[ q(2P) + 2Pq'(2P) = 0 \]  

(i)

with $P = P_{AA} = P_{BB}$. With compatibility the first-order condition for firm A is:

\[ 2q(2P) + 3Pq'(2P) = 0 \]  

(ii)

with $P = P_{AA} = P_{BB}$. Comparing (i) and (ii) and assuming that the second-order conditions are satisfied everywhere yield $P > P$.  

\(^6\)
Although this difference in price-cutting incentive always leads to higher equilibrium prices with compatibility, its effect on the firms' equilibrium profits depends on the form of competition that prevails. The intuition is as follows.

In our model each firm sells two complementary goods. If two such goods are sold by a monopolist, their prices will be lower than if each good were sold by a separate firm. This is so since the multiproduct monopolist realizes that cutting the price of one of his components increases the demand for both. In other words, the multiproduct firm internalizes the complementarity between the two products, while two single-product firms do not. Consequently, under similar cost conditions the profits of the multiproduct firm are higher than the sum of the profits obtained by two firms, each selling a single good.

We have just shown that firms internalize the complementarity effects more fully when their systems are incompatible than when compatibility prevails. When the two firms are local monopolists, it follows that prices are lower without compatibility. Moreover, the profits of an industry with compatible components are less than twice the profits of an industry with incompatible ones. This means that full internalization of complementarity effects does indeed increase profits when the firms do not compete directly.

When firms are direct competitors, however, this analysis no longer holds. It is still true that owing to the greater internalization of complementarity, each firm will set lower prices under incompatibility for any given level of its rival's prices. As the firms' reaction functions are now increasing in their rival's prices, however, such behavior drives the equilibrium prices farther down and reduces profits. This becomes especially clear as soon as the whole market is served, since the increased price-cutting incentives drive the equilibrium prices down without increasing the size of the total market: the monopolists' blessing has turned into a curse for the full competitors.

This analysis suggests that our results depend heavily on the assumption that each firm sells a full set of components. This is confirmed by a comparison of Table 1 with Table 2, where the two integrated firms have been replaced by four independent single-good producers and where incompatibility refers to an industry were only two different systems can be assembled. With such an industry structure, there is no difference in the degree of internalization of complementarity between the compatibility and incompatibility equilibria, since the firms always ignore these effects. The only impact of standardization is to increase variety and to augment the market area served at any given prices.

It follows that as long as it does not change the nature of competition (i.e., as long as local monopolies or full competition emerge in both subgames), the compatibility decision has no effect on equilibrium prices, so that the ratio between industry profits with and without compatibility goes from two to one as the reservation price increases. For intermediate values of the reservation price, however, the standardization decision affects the nature of competition in the last stage of the game, since direct competition between systems

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7 Sufficient conditions for this to be true (with constant marginal cost, \( c \), and symmetry) is that the marginal revenue of a single-product firm be everywhere decreasing in its own price and in the other good's price. Define \( MR_i \) and \( MR_j \) as the own- and cross-price derivatives of a single-product firm's marginal revenue and \( D_j \) as the cross-price derivative of a good's demand function. With symmetry the first-order condition for a single product firm is just

\[
MR(P^*_m) = c, \tag{iii}
\]

where \( P^*_m \) is the equilibrium price when the two products are sold by separate firms, while the first-order condition for a two-product monopolist is

\[
MR(P^*_m) + P^*_m D_j(P^*_m) = c, \tag{iv}
\]

where \( P^*_m \) is the equilibrium price of each good when they are both sold by the same firm. With \( MR_i < 0, MR_j < 0, \) and \( D_j < 0, \) (iii) and (iv) cannot both be satisfied if \( P^*_m > P^*_m. \) Therefore, \( P^*_m > P^*_m. \) See Brander and Eaton (1984) for a similar proof.
TABLE 2  Equilibrium Values for the Case of Four Independent Firms

<table>
<thead>
<tr>
<th>$C$</th>
<th>Incompatibility</th>
<th>Compatibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C \leq \lambda$</td>
<td>$P_I^* = \frac{C}{2}$</td>
<td>$P_c^* = \frac{C}{2}$</td>
</tr>
<tr>
<td></td>
<td>$\Pi_I^* = \frac{C^3}{32 \lambda^2}$</td>
<td>$\Pi_c^* = \frac{C^3}{32 \lambda^2}$</td>
</tr>
<tr>
<td>$\lambda \leq C \leq 2\lambda$</td>
<td>$P_I^* = \frac{10C - 11\lambda + \sqrt{7\lambda^2 - 28\lambda C + 4C^2}}{24}$</td>
<td>Simulations</td>
</tr>
<tr>
<td></td>
<td>$C$</td>
<td>$P_c^*$</td>
</tr>
<tr>
<td></td>
<td>$\frac{3\lambda}{2}$</td>
<td>.86$\lambda$</td>
</tr>
<tr>
<td></td>
<td>$2\lambda$</td>
<td>1.228$\lambda$</td>
</tr>
<tr>
<td>$2\lambda \leq C \leq 3\lambda$</td>
<td>$P_I^* = C - \lambda$</td>
<td>$9\lambda$</td>
</tr>
<tr>
<td></td>
<td>$\Pi_I^* = \frac{C - \lambda}{4}$</td>
<td>$5\lambda$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{11\lambda}{4}$</td>
</tr>
<tr>
<td>$C \geq 3\lambda$</td>
<td>$P_I^* = 2\lambda$</td>
<td>$P_c^* = 2\lambda$</td>
</tr>
<tr>
<td></td>
<td>$\Pi_I^* = \frac{\lambda}{2}$</td>
<td>$\Pi_c^* = \frac{\lambda}{2}$</td>
</tr>
</tbody>
</table>

arises more rapidly in a compatible industry. This explains why, even with four single-product firms, equilibrium prices can be higher when standardization prevails. When systems compete with each other, a given price cut captures fewer new consumers than when each system enjoys a local monopoly, because some of the consumers to be captured can get a positive consumer surplus by switching to another system. It follows that for intermediate reservation prices (i.e., $\lambda \leq C \leq 3\lambda$), the firms’ incentives to cut prices are lower, and thus equilibrium prices are higher where components are compatible.

4. Equilibria of the game

■ If the costs of standardization are prohibitively high (i.e., if $\alpha_A$ and $\alpha_c$ are larger than $\Pi_c^* - \Pi_f^*$), compatibility is never achieved. In the adaptor case compatibility arises as the unique equilibrium outcome if and only if $\Pi_c^* - \Pi_f^* \geq \alpha_A$. More precisely, there are two subgame-perfect Nash equilibria in pure strategies, one with firm $A$ building the adaptor and one with firm $B$ enforcing compatibility.\(^8\)

In the consensus case both compatibility and incompatibility can arise as equilibrium outcomes even if standardization costs are lower. There are two subgame-perfect Nash equilibria in pure strategies, one where both firms adopt the common technology and one where they choose their own incompatible standard. Both firms are better off in the compatibility equilibrium.\(^9\)

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\(^8\) With $\alpha_A = 0$ there is a third equilibrium, where both firms build the adaptor.

\(^9\) Also, compatibility would be the outcome of the unique subgame-perfect Nash equilibrium if the first stage of the game were to be played sequentially.
5. Welfare

Compatibility has two opposing effects on consumers. On one hand, the prices charged by the firms increase with compatibility, but on the other, system variety is increased so that the average distance travelled by consumers decreases.

All individuals are not affected equally by a move to compatibility. Consumers with a strong preference for one of the firms’ full systems are made unambiguously worse off, since they buy the same system as with incompatibility but are charged a higher price. The fortunes of consumers who, given the opportunity, would mix components sold by different firms are less clear. They get closer to their ideal specifications (by as much as \( \lambda \) for an individual located at \((0, 1)\)), but they must pay a higher price. As \( P^*_c - P^*_f \) is always smaller than \( \lambda \), however, some of these consumers are always made better off by standardization.

The effect of standardization on consumer surplus depends on the relative values of \( C \) and \( \lambda \). For low reservation prices consumer surplus is higher with compatibility than with incompatibility. As the reservation price increases, however, the difference in equilibrium prices tends to grow, while the variety-increasing effect becomes weaker, so that consumer surplus is larger without compatibility for all \( C \) greater than 2.2\( \lambda \).

In the absence of standardization costs, social surplus is always larger when firms sell compatible components, so that compatibility is always socially desirable. It will also always be achieved except in the consensus case when the firms happen to choose the (dominated) incompatibility equilibrium. With positive costs of standardization, however, the firms’ incentives to standardize can be excessive or insufficient, irrespective of how compatibility can be achieved.

In the consensus case compatibility prevails if and only if \( \Pi^*_c - \Pi^*_f > \alpha_c \), while it is socially desirable if and only if \( CS^*_c - CS^*_f > 2[\alpha_c - (\Pi^*_c - \Pi^*_f)] \). Comparing the two conditions shows that, as long as compatibility increases consumer surplus, there exist standardization costs such that the firms decide to produce incompatible systems although standardization is socially optimal. Conversely, if consumer surplus is higher with incompatibility, there are values of \( \alpha_c \) for which the firms sell compatible components although incompatibility is socially preferable.\(^{10}\)

\(^{10}\) More precisely, there is excessive standardization if \( CS^*_f > CS^*_c \) and

\[
[CS^*_c - CS^*_f]/2 + \Pi^*_c - \Pi^*_f < \alpha_c < \Pi^*_c - \Pi^*_f,
\]

while incompatibility will unduly prevail if \( CS^*_c > CS^*_f \) and \( \Pi^*_c - \Pi^*_f < \alpha_c < (CS^*_c - CS^*_f)/2 + \Pi^*_c - \Pi^*_f \).
In the adaptor case compatibility is achieved if and only if $\Pi^* - \Pi^f < \alpha_d$, while it is socially optimal if and only if $(CS^* - CS^f + \Pi^* - \Pi^f) > \alpha_d - (\Pi^* - \Pi^f)$. Socially excessive standardization can only arise if compatibility significantly decreases consumer surplus, while there are values of $\alpha_d$ for the firms’ incentive to standardize that are socially insufficient even when consumer surplus is lower with compatibility.\(^{11}\)

The values of $\alpha_d$ and $C$ for which the firms’ compatibility decisions are not socially optimal are shown in Figure 4 for the adaptor case (and $\lambda = 1$).\(^{12}\)

6. Robustness and extensions\(^{13}\)

- The ranking of prices and profits, the nature of the equilibria, and the welfare analysis remain valid if zero/one demands are replaced by linear demands at each point, i.e., if a consumer purchases $X = C - D(d_1 + d_2) - DP$ units of the system with the lowest total price $d_1 + d_2 + P$. An interesting difference is that with linear demands the variety-increasing effect persists even when the whole market area is served, since compatibility decreases $(d_1 + d_2)$ for some consumers and shifts their demand function upward.\(^{14}\)

The assumption that consumers are uniformly distributed on a square affects the results in two ways. First, it implies that there is no correlation between the consumers’ preferences for the two components. If there were some systematic brand preference, the consumers would be distributed more densely along the Southwest–Northeast diagonal of the square, and the variety-increasing effect of standardization would be weaker. This situation can be analyzed by cutting off the Northwest and Southeast corners of the square and concentrating the unit mass of consumers on the remaining area. It is easily shown that, although the quantitative differences are smaller, compatibility still leads to prices and profits that are at least as high as those prevailing with incompatibility. Only when all the consumers are located on the diagonal are the two equilibria equivalent.

Second, when the whole market is served, the boundary between the consumers served by firm $A$ and those served by firm $B$ is longer with incompatibility than with compatibility, since the diagonal of the square is longer than its side. This biases the results in favor of standardization, since it makes the firms’ incentive to decrease price relatively greater when systems are incompatible than when compatibility prevails. Even if the length of the market boundaries were the same, however, each firm would still have stronger incentives to decrease prices without compatibility, since a given price cut would increase demand for both of the firm’s components. This can be verified by assuming that consumers are uniformly distributed on the circle inscribed in the square. With such a shape the market boundary will be of equal length in the symmetric compatibility and incompatibility equilibria. It can be shown that $P^x = \lambda \Pi^x, P^y = \lambda \Pi^y (\sqrt{2}/2), \Pi^x = \lambda \Pi^2/2, \Pi^y = \lambda \Pi^2 (\sqrt{2}/4)$ so that standardization still yields higher prices and profits than incompatibility.\(^{15}\)

While our results are preserved when the market boundary has the same length with or without compatibility, they could be reversed if the market boundary were considerably shorter with incompatibility than with compatibility. Such a situation can occur if the firms differ in their marginal costs of production. The length of the relevant diagonal decreases as one firm appropriates more of the market, while the length of boundary remains unchanged with compatibility. For small differences in marginal costs both firms are better off with compatibility than with incompatibility. If one firm is much more efficient than the other,

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\(^{11}\) There is excessive standardization if $\alpha_d$ is such that $CS^* - CS^f + 2[\Pi^* - \Pi^f] < \alpha_d < \Pi^* - \Pi^f$, while there is excessive incompatibility whenever $\Pi^f - \Pi^* < \alpha_d < CS^* - CS^f + 2(\Pi^* - \Pi^f)$.

\(^{12}\) In the consensus case, $SS^* - SS^f$ must be replaced by $[SS^* - SS^f]/2$.

\(^{13}\) The derivations of the results presented in this section can be obtained from the authors.

\(^{14}\) See Matutes and Regibeau (1987) for a detailed analysis of this case.

\(^{15}\) To simplify the computations, these values were derived for a circle inscribed into a square of area 4.
however, it will prefer incompatibility, while its less efficient rival still favors standardization.\textsuperscript{16} In such a case compatibility only prevails if it can be enforced unilaterally by the less efficient firm.

Finally, as pointed out by Tirole (1987), the firms only have an incentive to produce compatible components as long as they do not try to exclude their rival from the market. If a dominant firm were trying to prevent entry in the industry, it might well attempt to preserve incompatibility. Such a strategy might deter entry, since it reduces industry demand and makes the incumbent respond to entry with more aggressive pricing than if compatibility prevailed.\textsuperscript{17}

7. Conclusion

We have developed a stylized model where two firms produce two-component systems. The firms must decide whether to make their systems compatible with their rival’s before competing in prices. The symmetric perfect Nash equilibrium of this two-stage game has been shown to depend on how compatibility can be achieved. If it can be enforced unilaterally (the adaptor case), then product compatibility arises and is always socially optimal provided that there are no costs to achieving standardization. If compatibility requires a consensus, however, there are two equilibria in pure strategies, one involving standardization and the other leading to incompatibility.

This, of course, does not mean that standardization will generally tend to prevail or that it is always desirable. Any cost incurred to achieve compatibility, such as additional research and development expenditures, will reduce the firms’ incentives to produce compatible components and should be deducted from the social surplus before making any welfare judgement. It has indeed been shown that if the costs of standardization and the reservation prices are sufficiently high, the firms will tend to choose compatibility although an incompatible industry would be socially preferable. Similarly, for low reservation prices socially desirable compatibility might not obtain. Also, network externalities, which were omitted from our model, are certainly important in many industries and will, other things being held equal, increase the desirability of product standardization. Their impact on the firms’ incentives to standardize, as analyzed by Katz and Shapiro (1985) should also be weighed against the incentives identified in this article before any conclusion is drawn. Finally, the adoption of a common standard by independent firms is an essentially dynamic process. This dimension, examined by Farrell and Saloner (1985, 1986b) and Katz and Shapiro (1986) cannot, of course, be captured in our purely static model.

We have also argued that by increasing the number of systems available, product compatibility increases the range of consumers’ choice, which seemingly contradicts Farrell and Saloner’s claim that product standardization necessarily reduces product differentiation. But the two propositions refer to two different aspects of product diversity. On the one hand, product compatibility increases the number of systems from which consumers can choose. On the other hand, achieving compatibility might require that components be more similar in other respects. Thus, the compatibility that prevails in the home stereo industry increases the number of stereo systems that a consumer can assemble, but it might also have been achieved at the cost of reducing the variety of features displayed by, for example, the tape decks produced by different manufacturers. Moreover, even if there were no such

\textsuperscript{16} If firm A has zero marginal cost, both firms prefer compatibility as long as firm B’s marginal cost is lower than 1.4λ. If firm B’s marginal cost is larger than that, firm A prefers incompatibility. Firm B still favors standardization because, as \( P^*_B < P^*_A \), it can appropriate a disproportionate share of the revenues from the sales of mixed systems.

\textsuperscript{17} If there is an entry fee, \( E \), and \( \Pi^*_F > E > \Pi^*_I \), incompatibility effectively deters entry. This is a profitable strategy if monopoly profits are higher than duopoly profits with compatibility.
technical constraints, the degree of product differentiation between similar components might not be independent of whether they are compatible across manufacturers. An interesting extension of the analysis in this article would be to allow firms to choose both their location and their price. We hope to address this issue in a future article where, to avoid the familiar nonexistence problems, we shall assume that entry occurs sequentially and involves some sunk cost.

The most significant contribution of this article might well be to underline the importance of explicitly modelling systems as combinations of components. Not only does such an approach reveal several effects that had been ignored in previous analyses of standardization, but it also is a necessary first step toward the analysis of more realistic market structures. Treating systems as single goods, or implicitly assuming either that every firm in the industry produces a full line of components or that firms sell a single component to consumers who have already bought the rest of the system, does not always fit observed industry patterns.

Appendix

- If the components sold by different firms are fully compatible, the equilibrium prices, profits, and consumer surplus are obtained as follows.

- **Local monopolists.** A consumer buys one unit of system $X_{ij}$ if $C - \lambda (d_1 + d_2) - P_{1i} - P_{2j} \geq 0$ so that firm $A$’s profit can be written as:

$$\Pi_A = \frac{P_{1A} + P_{2A}}{2\lambda^2} [C - P_{1A} - P_{2A}]^2 + \frac{P_{1A}}{2\lambda^3} [C - P_{1A} - P_{2A}]^3 + \frac{P_{2A}}{2\lambda^3} [C - P_{1A} - P_{2A}]^3.$$  

Maximizing $\Pi_A$ with respect to $P_{1A}, P_{2A}$ and imposing symmetry in the first-order conditions yield $P_A^* = C/5$ and thus $\Pi_A^* = 18C^3/125\lambda^3$. At these prices the areas served by different systems are disjoint if $C < 5\lambda/6$. The consumer surplus is:

$$CS = 4 \int_0^{(3C/5b)} \int_0^{(3C/5b) - 31} [(3C/5) - \lambda g_1 - \lambda g_2] dg_2 dg_1.$$  

- **Direct competitors with a partially served market.** Firm $A$’s profit function can be written as:

$$\Pi_A = \frac{P_{1A} + P_{2A}}{4} \left[ \left( 1 + \frac{P_{2B} - P_{1A}}{\lambda} \right) \left( 1 + \frac{P_{1B} - P_{1A}}{\lambda} \right) - \frac{C}{\lambda} \right]^2$$  

$$+ \frac{P_{2A}}{4} \left[ \left( 1 + \frac{P_{1A} - P_{2B}}{\lambda} \right) \left( 1 + \frac{P_{1B} - P_{1A}}{\lambda} \right) - \frac{C}{\lambda} \right]^2$$  

$$+ \frac{P_{2A}}{4} \left[ \left( 1 + \frac{P_{1A} - P_{1B}}{\lambda} \right) \left( 1 + \frac{P_{2A} - P_{2B}}{\lambda} \right) - \frac{C}{\lambda} \right]^2.$$  

Maximizing $\Pi_A$ with respect to $P_{1A}, P_{2A}$ and using symmetry yield

$$P_2^* = (1/16)(6C - 6.5\lambda).$$  

At these prices the market remains partially served as long as $C - 2P^*_2 < \lambda$ or $C < 3\lambda$. The consumer surplus is given by:

$$CS = 4 \int_0^{C/\lambda - P/\lambda - 1/2} \int_0^{1/2} [C - P - \lambda g_1 - \lambda g_2] dg_1 dg_2 + \int_0^{1/2} \int_0^{C/\lambda - P/\lambda - 1/2} [C - P - \lambda g_1 - \lambda g_2] dg_1 dg_2.$$  

- **Direct competitors with the whole market served.** Firm $A$’s profits can be written as:

$$\Pi_A = \left[ \frac{P_{1A} + P_{2A}}{2\lambda} \right] \left[ \frac{1}{2} + \frac{P_{2B} - P_{1A}}{2\lambda} \right] + \left[ \frac{1}{2} + \frac{P_{1A} - P_{1B}}{2\lambda} \right] \left[ \frac{1}{2} + \frac{P_{2A} - P_{2B}}{2\lambda} \right]$$  

$$+ \frac{P_{2A}}{2} \left[ \frac{1}{2} + \frac{P_{1A} - P_{1B}}{2\lambda} \right] \left[ \frac{1}{2} + \frac{P_{2B} - P_{2A}}{2\lambda} \right].$$
Maximizing $\Pi_4$ with respect to $P_{14}$, $P_{24}$ and using symmetry yield $P_{4}^* = \lambda$ and $\Pi_4^* = \lambda$. The consumer surplus is given by:

$$CS = 4 \int_0^{1/2} \int_0^{1/2} \{C - 2\lambda - \lambda g_1 - \lambda g_2\} dg_1 dg_2.$$ 

References


