In Electronic Services Networks,
M.E. Guerrin-Calvert and
S.S. Wildman (eds), Praeger,
New York, 1991.

3

Compatibility and the Creation of Shared Networks

Nicholas Economides

Many networks start out as self-contained private (or proprietary) networks. It is often the case that over time private networks link up to form shared networks. However, this does not always happen. Until Citicorp joined the nationwide Cirrus system in early 1991, both outcomes could be seen in different automatic teller networks in the New York City area. Citicorp's extensive network of automatic teller machines (ATMs) was private and essentially restricted to use by Citicorp's customers only, while the New York Cash Exchange (NYCE) network was a shared joint-venture network of a number of banks. In this chapter, I develop an economic model to explore the incentives for private networks to form shared networks. The model has broader applications to product systems generally. More specifically, this chapter explores the incentives for private networks to adopt compatible specifications so that transactions across networks are feasible and at no extra cost due to incompatibilities.

A private network can vary its degree of compatibility with another private network. In general, an adapter is required for transactions across networks, and each private network contributes to the cost of the adapter through its choice of specifications. It is shown that, even in the absence of binding agreements, full compatibility (zero adapter cost) will emerge at equilibrium provided that the demands for each of the potential transactions are of the same size. Various degrees of incompatibility and limitations of access across private networks will emerge when this condition does not hold. In particular, when demand for hybrid (across networks) transactions is small, all private networks prefer to have incompatibility and restrict access across the networks. If only one private network has a large demand (because of good reputation or high

quality of service) then it will opt for incompatibility while the smaller private network desires compatibility.

The next section introduces the terminology and analytical framework required to examine the incentives for compatibility. An example is presented that captures the intuition underlying the formal analysis and illustrates the primary findings of the formal analysis developed in the remainder of the chapter. The formal model is introduced in its simplest form in the third section. In the following sections, I discuss the symmetric case, where the demand for (hybrid) transactions across the private networks is equal to their internal transactions demands, followed by the asymmetric case, where the demand for hybrid transactions falls short of the demand for transactions within the private networks. The model is elaborated to allow for the bundling of services within private networks and the possibility that different adapters are required for different hybrid transactions. I conclude the formal analysis by showing that the conclusions of the previous analyses extend to a model that allows for sequential decisions, with the decisions on specifications taken at an earlier stage than the decisions on prices.

BASIC FRAMEWORK

Many complex goods are composed of simpler *elementary goods*, which in many cases are sold separately. For example, the good "phone call from X to Y" requires use of phone appliances at X and at Y as well as the use of a network that allows the transmission of signals from X to Y. This network may include the local networks of locations X and Y plus a long-distance network. Note that each of the elementary goods is complementary with the other, since their combination allows the consumer to purchase the *composite good* that he desires, the phone call from X to Y.

The elementary goods can be thought of as *components* and the composite goods as *systems*. For example, consider a personal computer that is composed of a central processing unit (CPU), a video monitor, and a keyboard. Each of these three elementary goods can be considered a component and their combination is a system.

In general there will be a number of elementary goods of each type. Elementary goods of the same type are obviously substitutes. The different combinations of elementary goods create systems that are also seen by the consumers as substitutes. IBM and Compaq CPUs are substitutes. So are IBM and Compaq monitors. And the four systems (pure IBM, pure Compaq, and the two hybrids) are also substitutes for each other.

The ability of all elementary goods (or components) to be combined costlessly with all elementary goods of a different type to produce functioning composite goods (or systems) is defined as *full compatibility*. Compatible elementary goods can be thought of as constituting a *network*. Consider the composite good "cash withdrawal through an ATM." It is composed of at least

two elementary goods that are complementary with each other—the use of the ATM and the use of the services of a bank from which the funds are withdrawn. Full compatibility of all elementary goods means that a cash withdrawal from any bank by using any ATM is feasible. Thus, under full compatibility, "there is an ATM network." Of course, it is the *vertical* connection between ATMs and banks and *not a horizontal* connection between ATMs that constitutes the (vertical) network.[1] Thus, the existence of a (vertical) network is contingent upon compatibility between complementary elementary goods.

This chapter will analyze the conditions under which full compatibility and thereby networks will emerge from the noncooperative behavior of firms—that is, without binding agreements between the firms. Thus, firms are assumed to consider only their individual incentives in making compatibility decisions and not the collective industry-wide interests. Parties are allowed to agree on compatibility specifications, but the agreements are based on the individual incentives of the parties rather than their collective interests. Firms are not allowed to enter into agreements with punishments for deviation from them.

A significant proportion of the existing literature on compatibility has focused on the issue of "network externalities," a catchall term for positive consumption or production externalities. For example, in a network externalities framework, the buyer of the last unit of a good has a higher benefit than the buyer of the first unit because the sale of the earlier units has created some benefits in a related dimension. The large sales of VHS video recorders/players and the implied demand for VHS tape rentals has created over time large VHS tape libraries that benefit the later buyers of VHS players. Similarly, later buyers of Lotus 1-2-3 find already-trained personnel and can reap higher benefits. In a world of network externalities, it pays manufacturers that arrive late in the market to adopt the specifications of the existing network or at least to make their product compatible with the existing network specifications. For example, Microsoft Excel, arriving late in the spreadsheet market for MS-DOS computers that was dominated by Lotus 1-2-3, is able to read 1-2-3 files. Borland's Quattro, also arriving late in the same market, is able to both read and write 1-2-3 files. The complementarity between the pair of goods that exhibit network externalities is self-reinforcing. Thus, the large tape libraries of VHS tapes increase the value and sales of VHS players; the high sales of VHS players create an even higher demand for larger VHS tape libraries.[2]

Although the existence of network externalities can easily explain the expansion of an existing network and the adherence of latecomers to old standards, it is not sufficient to explain the creation of a shared network out of preexisting private networks.

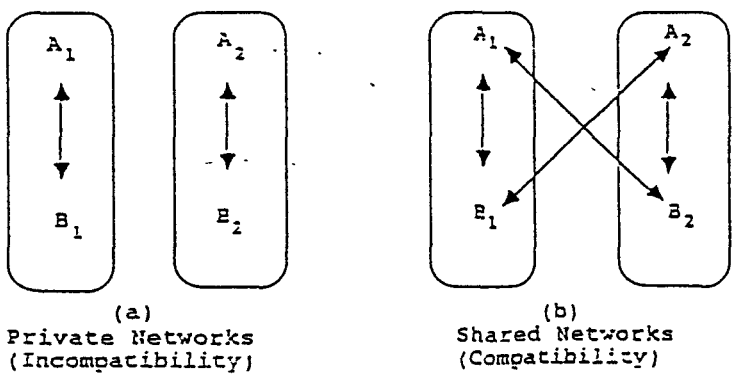
Suppose there are two types of elementary goods, A (standing, for example, for ATM) and B (standing, for example, for bank), and each firm produces a good of each type. To start with, consider the case of two elementary goods of each type. Elementary goods of different types can be combined in a 1:1 ratio

to create composite goods that are demanded by consumers. Suppose there are two firms, $i = 1, 2$, and firm i sells products A_i and B_i.

In Figure 3.1, the composite goods are denoted by double-pointed arrows. Ownership is denoted by boxes enclosing the products produced by the same firm. The elementary goods produced by the same firms are readily and costlessly combinable yielding systems A_1B_1 and A_2B_2. If each firm decides to make its products *incompatible* with the products of the opponent, then only these two composite goods will exist. This is shown in Figure 3.1a. Then there are two incompatible private networks. Alternatively, when both firms decide to make their elementary goods fully compatible with those of the opponent, the hybrid products A_1B_2 and A_2B_1 also become available as in Figure 3.1b. Now there are four composite products available to the consumer. This is a "shared" network. The shared network is created by the decisions of firms to make their elementary goods compatible with those of the opponents.

In what regime will firms have higher prices and profits? Economides (1989a) discusses this question in the context of differentiated goods. For example, ATMs can be at different physical locations while banking services are differentiated in features of variety such as pricing schedules, deposit requirements, locations, risk, etc. It is shown that under fairly general conditions,[3] firms will have higher prices and profits under compatibility. The intuition for this result is relatively simple. Imagine that good A is computer CPUs, good B is monitors, and firm 1 is IBM. Suppose that we are in the world of incompatibility of Figure 3.1a and IBM contemplates a price increase in its computer system A_1B_1. Similarly, suppose IBM contemplates the same price increase in the price of its CPU (A_1) in the world of compatibility. Equal price increases create equal demand responses as long as the demand for hybrids is of the same size as the demand for single-producer goods. But now, in the case of incompatibility, IBM's demand response is in units of systems, while in the case of

Figure 3.1
Network Compatibility Relationships



compatibility IBM's demand response is in units of CPUs. Multiplying with the corresponding prices, we see that the value (profit) response is higher in the case of incompatibility. In the world of compatibility, only sales of CPUs are lost as a result of the price increase and therefore the profit loss is smaller. This prompts IBM to set a *lower price* in the regime of incompatibility where *demand appears (to IBM) to be more elastic*. Profits follow the direction of prices, so that higher profits are realized in the regime of full compatibility. Higher profits lead more firms to enter in the market under compatibility. Thus, under compatibility there will be more varieties available to consumers for two reasons: first because more firms will operate in the market, and second because all the cross (hybrid) combinations are available under compatibility that are not available under incompatibility. It is evident that the standardization implied by compatibility is in no conflict with lots of varieties being available at equilibrium. Therefore, comparing a shared network with a collection of private networks, we find a larger number of competitors, a much larger number of composite goods, and higher prices in a shared network.

Firms are usually active participants in the decision processes that define the degree of compatibility in the marketplace. Thus, a comparison of the two regimes, the regime of compatibility (shared network) and the regime of incompatibility (private networks), is not sufficient to determine which will emerge. One needs to analyze how the individual decisions of the firms result or do not result in full compatibility and the creation of shared networks. This chapter explicitly models the decisions of competing firms on the choice of compatibility, and thus the creation of shared networks.

In general, there will always exist some technologically feasible way to make two components work together as a system through the addition of an adapter, interface, or gateway. Of course, the required adapter can be extremely expensive and therefore not used, but the possibility of its use exists in general. Thus, the degree of compatibility of two components is measured by the cost of the adapter that is required to allow them to function together as a working system. Full compatibility means that an adapter of zero cost is required. Varying degrees of incompatibility are reflected in the size of adapter costs.

Component-producing firms can choose the specifications of their components to make them compatible or incompatible in some degree with the complementary components produced by competitors. Owners of private networks can use technical specifications or other means to restrict access to the elementary goods of their network by outsiders. In this sense, any incompatibilities introduced are nuisance incompatibilities, designed to limit competition. They are not technologically necessary.

Some readers may already be wondering how it could possibly be that any firm would have an incentive to introduce or tolerate incompatibilities. The previous discussion may lead some readers to conclude that compatibility is obviously the equilibrium. This is not true. One needs to recognize that there

are two potentially opposing incentives in the combination of two private networks and the creation of a shared one. The first incentive is the increase in demand that accompanies the merger of private networks. It is a strong incentive for the creation of a shared network. For example, if originally there are two banks, each with its private and distinct ATM network, the unification of the networks will allow access to bank 1 from ATMs owned by bank 2, thereby creating an increase in demand for the banking services of bank 1. The second incentive is more subtle. Remember that the ownership structure does not change as the networks become shared. A merger of two private networks can increase competition between the owners of these two networks. Prices of banking services and of ATM services are not obviously guaranteed to rise as a result of the combination of the two private networks. A significant part of the rest of this chapter analyzes the balance of these two incentives. I show that when the demand incentive is strong—that is, when the demand for hybrid transactions is strong relative to the demand for transactions within the private networks, then the demand incentive outweighs the competitive effects of compatibility and firms prefer compatibility. However, when the demand for hybrids is small, the potential demand gain from the creation of a shared network is overshadowed by the concurrent increase in competition. Then each private network will prefer to be inaccessible and separate from other private networks.

THE STARTING MODEL

Suppose that there are two elementary goods of each type, A_1, A_2, B_1, and B_2. For concreteness, consider A_1 and A_2 to be competing ATMs and B_1 and B_2 to be competing banks. Assume that composite goods A_1B_1 and A_2B_2 require no adapters, but hybrid goods A_1B_2 and A_2B_1 require adapters of cost R. R is the extra cost of doing business across the private networks. Let the prices of elementary goods A_1,A_2 be p_1, p_2 and of goods B_1, B_2 be q_1, q_2 respectively. Then the four composite goods in the market are available at the prices shown in Table 3.1.[4]

Each firm can affect the price of an adapter through its choice of specifica-

Table 3.1
Composite Goods and Corresponding Prices with No Bundling

Composite Good	Price
A_1B_1	p_1+q_1
A_1B_2	p_1+q_2+R
A_2B_1	q_1+p_2+R
A_2B_2	p_2+q_2

tion of components. It will be assumed that each firm can contribute positively to the cost of the adapter but cannot decrease the cost attributed to incompatibilities introduced by other firms. A simple functional form exemplifies this assumption. Let x, $x_h \geq x \geq 0$, reflect the cost attributed to incompatibilities introduced by firm 1 and y, $y_h \geq y \geq 0$, reflect the cost of those attributed to firm 2. Then $R = x + y$. Thus, I assume that an incompatibility introduced by one firm cannot be wiped out by the other firm. Incompatibilities can be introduced in many dimensions of technical specifications, and it is hard for one firm to anticipate and counteract each incompatibility introduced by the opponent.[5] It will be assumed that adapters are produced by a competitive sector and sold at cost.[6]

The demand for each of the four products A_1B_1, A_1B_2, A_2B_1, and A_2B_2, is a function of its own price, the price of the composite good that differs from it in the second component, the price of the composite good that differs in the first component, and the price of the composite good that differs in both components. We can write these demand functions as follows:

$$D^{11} = D^{11}(p_1 + q_1,\ p_1 + q_2 + R,\ q_1 + p_2 + R,\ p_2 + q_2)$$
$$D^{12} = D^{12}(p_1 + q_2 + R,\ p_1 + q_1,\ p_2 + q_2,\ p_2 + q_1 + R)$$
$$D^{21} = D^{21}(p_2 + q_1 + R,\ p_2 + q_2,\ p_1 + q_1,\ p_1 + q_2 + R)$$
$$D^{22} = D^{22}(p_2 + q_2,\ p_2 + q_1 + R,\ p_1 + q_2 + R,\ p_1 + q_1)$$

where the first superscript on the Ds identifies the ATM owner and the second superscript identifies the bank.

Vertically integrated firm i, $i = 1, 2$, sells both A_i and B_i. A_1 is sold as part of A_1B_1 and A_1B_2, since a bank 1 ATM can be used to make a transaction with either bank 1 or bank 2. Thus, sales of A_1 are $D^{11} + D^{12}$. Similarly, since B_1 is sold as part of A_1B_1 and A_2B_1, sales of B_1 are $D^{11} + D^{21}$. Assuming zero costs,[7] the profits of firm 1 are

$$\pi^1 = p_1(D^{11} + D^{12}) + q_1(D^{11} + D^{21})$$

Similarly, profits for firm 2 are

$$\pi^2 = p_2(D^{22} + D^{21}) + q_2(D^{22} + D^{12})$$

SYMMETRIC DEMAND

An increase in the cost of the adapter, R, increases the price of goods A_1B_2 and A_2B_1 that represent transactions across networks owned by different firms. The demand for A_1B_2 and A_2B_1 falls while the demands for the other two composite (nonhybrid) goods A_1B_1 and A_2B_2 increase. What is the balance of the demand and profit changes? It depends on the size, shape, and elasticities of the demand functions of the four composite goods. In practice these can be

estimated. Below I provide sufficient conditions for the firms to choose compatibility.

ASSUMPTION 1: *The demands for the four composite goods are symmetric so that all four can be represented by the same function:*

$$D^{11}(X,Y,Z,W)=D^{12}(X,Y,Z,W)=D^{21}(X,Y,Z,W)=D^{22}(X,Y,Z,W)$$

This assumption ensures that the size and the shape of the demand functions are the same for all four composite goods. In particular, the demand for hybrids is of equal size and elasticity as the demand for single-producer goods. This means that the willingness to pay for any of the four composite goods is the same if all four are offered at equal prices. Assumption 1 does *not* restrict the own-elasticity and the cross-elasticities of demand in the substitution of banking or ATM services.

ASSUMPTION 2: *An equal increase in the prices of all four goods decreases the demand for each good.*

This is a very natural assumption. When all goods become more expensive and income is held constant, it is reasonable that demand falls for all products.

ASSUMPTION 3: *The demand functions are linear. The representative demand* D^{11} *is*

$$D^{11}=a-b(p_1+q_1)+c(p_1+q_2+R)+d(p_2+q_1+R)+e(p_2+q_2)$$

where a, b, c, d, e>0.

The linear structure of demand is not a significant restriction. The results carry through with minor modifications for general demand functions. Note that Assumption 2 implies that $b>c+d+e$. The degree of substitution between composite goods that differ only in the second elementary good is measured by c. In the ATM example, c represents the substitutability between transactions with different banks at the same ATM. Thus c essentially represents substitutability of banking services. Similarly, d represents substitutability between composite goods that differ in the first elementary good only—that is, substitutability between different ATMs. Finally, e represents substitutability between composite goods that differ in both dimensions (ATM and bank).

Consider now a setup where prices and product specifications are chosen simultaneously. Suppose that firm 1 decides to increase the price R of the adapter. The effect on profits is

$$\partial\pi^1/\partial R=(-b+c+d+e)(p_1+q_1)<0$$

THEOREM 1: *Under Assumptions 1–3, firms choose noncooperatively to set adapters' cost to zero—that is, to make their components fully compatible with those of the other firms. Owners of private networks will merge them into a shared network.*

The intuition of the proof follows. Consider first the sales of ATM services by firm 1—that is, sales of product A_1. Sales of A_1 embodied in A_1B_1 increase with the cost of the adapter, R, according to $c+d>0$, and sales of A_1 embodied in A_1B_2 decrease with the cost of the adapter, R, according to $-b+e<0$. The total effect on sales of A_1 when the price of R increases is the sum of the two effects, $-b+c+d+e$, equivalent to the effect of an equal increase in all prices. By Assumption 2, this effect is negative. Therefore an increase in the price of the adapter decreases sales of A_1. Similarly, it decreases sales of B_1 and profits of firm 1. It follows that each firm will choose to minimize the cost of the adapter so that at equilibrium $R=0$. Each firm will try to achieve full compatibility with its competitors. A shared network will be the equilibrium.

Theorem 1 can easily be extended to a world of three or more firms, each producing two components. For example, if there are three component-producing firms, products 11, 22, and 33 need no adapter, while products 12 and 21 require an adapter of cost $x+y$, products 13 and 31 require an adapter of cost $x'+z'$, and products 23 and 32 require an adapter of cost $y'+z$. Firm 1 chooses x and x', firm 2 chooses y and y', and firm 3 chooses z and z'. It is not difficult to extend the arguments made for the two-firms problem and show that at equilibrium all adapters will cost zero—that is, $x=x'=y=y'=z=z'=0$, and there is full compatibility.

COROLLARY 1: *Full compatibility characterizes the equilibrium of $n\geq 3$ firms each producing two components.*

The result of full compatibility can also be extended to a world of systems composed of as many components as producers, with each firm producing each type of component. For example, when three components are required for a system there are twenty-seven (i.e., 3^3) systems available, starting with 111, 121, 131, 211, 221, 231, 311, 321, 331, 112, 122, 132, etc. Suppose that each firm controls a part of the adapter's cost through its decisions on the design of its components. Then the problem is very similar to the one discussed above. The proof that full compatibility arises as a noncooperative equilibrium is a straightforward repetition of the previous arguments.

COROLLARY 2: *Full compatibility characterizes the equilibrium of $n\geq 3$ firms each producing* n *components.*

ASYMMETRIC DEMAND

The crucial assumption for Theorem 1 and Corollaries 1 and 2 is that the demand for hybrids is equal to the demand for single-producer composite goods—

that is, Assumption 1. If this is not the case, compatibility may not result. Suppose that the demand for single-producer composite goods is large compared to the demand for hybrids. This may be because consumers lack confidence in composite goods made up of elementary goods of different producers. It may also be that because of historical reasons there are functions of an ATM that are not fully utilized in a transaction that involves a bank that does not own that particular ATM. For example, if a customer has a number of accounts, all accessible through the same magnetic card, an ATM belonging to a different bank may have trouble fully identifying the accounts with the customer. Another reason for low demand for hybrids could be that ATMs are located at the same location as the bank that owns them and consumers rarely travel to other locations.

When the demand for hybrids is small, an increase in the price of the adapter has a small negative effect on profits generated from sales of hybrid systems, but it has a significant positive effect on profits generated from sales of single-producer systems. Thus an increase in the price of the adapter can result in higher profits. Then firms will choose incompatibility.

For concreteness suppose that the demand for hybrids is a scale-down of the demand for single-producer systems. Assumption 1 is replaced by

$$kD^{11}(X,Y,Z,W)=D^{12}(X,Y,Z,W)=D^{21}(X,Y,Z,W)=kD^{22}(X,Y,Z,W),\ 0<k\leq 1$$

Then the effects of price increases on the demand for hybrids are smaller than on the demand for single-producer systems. The rate of change in sales of composite good A_1B_1 induced by the increase in R is $c+d>0$, and the rate of change in sales of system A_1B_2 is $k(-b+e)<0$. Thus the total effect on the sales of A_1 is $c+d+k(-b+e)$. Similarly, the total effect on the sales of B_1 is the same, $c+d+k(-b+e)$. For high k including $k=1$—that is, for nearly equal demand for hybrids and single-producer goods—this effect is negative. But there exists a $k_1<1$ such that for $k=k_1$ this effect is zero:

$$\partial\pi^1/\partial R=c+d+k(-b+e)=0\Leftrightarrow k=(c+d)/(b-e)\equiv k_1$$

When the demand for hybrids is small, $k<k_1$, the increase in sales of A_1B_1 dominates the decrease in sales of A_1B_2, and the total effect is positive,

$$\partial\pi^1/\partial R=[c+d+k(-b+e)](p_1+q_1)>0$$

Then each firm will prefer to introduce incompatibilities. At equilibrium both firms choose the highest degree of incompatibility possible, $x=x_h$, $y=y_h$, and $R=x_h+y_h$.

THEOREM 2: *If the demand for hybrids is sufficiently small compared to the demand for single-producer systems, all firms choose total incompatibility.*

In the above setting, firms have the same incentives on the question of compatibility because none of the private networks has a demand advantage. However, in many markets one private network has a demand advantage. It may be the reflection of good reputation or higher quality for both of its elementary goods. It could also be the result of the fact that both the bank and the ATM of one network are located in an area of high demand for their services.

Suppose that product A_1B_1 has high demand while demand is small both for hybrids A_1B_2 and A_2B_1 and for the single-producer system of firm 2, A_2B_2.

$$D^{11}=(X, Y, Z, W)=D^{12}(X, Y, Z, W)/k=D^{21}(X, Y, Z, W)/k$$
$$=D^{22}(X, Y, Z, W)/L,$$

with $0<k, L\leq 1$. Demand for hybrids A_1B_2 and A_2B_1 is k times the demand of A_1B_1; and the demand for A_2B_2 is L times the demand for A_1B_1. The relative size of the demand for the small private network and the demand for hybrids is important in the decision of compatibility as seen below.

In this setup, we expect that the large private network (firm 1) will act as in the previous situation when L was one. As before, the effects of an increase in the adapter's price R on sales of products A_1 and B_1 and on profits are

$$\partial(D^{11}+D^{12})/\partial R=\partial(D^{11}+D^{21})/\partial R=c+d+k(-b+e) \tag{3.1}$$

$$\partial\pi^1/\partial R=(p_1+q_1)[c+d+k(-b+e)] \tag{3.2}$$

As in the previous case, for large $k>k_1$ (including $k=1$), the private network with the demand advantage (firm 1) chooses compatibility because expression (3.2) is negative. However, for $k<k_1$ the large private network will choose incompatibility because the demand reward for compatibility is small (coming from the small demand for hybrids) and does not compensate it for the increase in competition.

The incentive for compatibility for the small private network (firm 2) is stronger because the difference between its single-producer demand and the demands for hybrids is smaller for the small private network (than for the large one). Remember that the demand for each of the hybrids is k times the demand for product A_1B_1, while the demand for product A_2B_2 is L times the demand for product A_1B_1 and both k and L are less than one. Thus there is a strong demand reward for firm 2 for a decision to minimize incompatibilities and it may compensate it for the increased competition even when firm 1 chooses differently.

The effect of an increase in the adapter's price R on the sales of products A_2 (and B_2) is

$$\partial(D^{22}+D^{21})/\partial R=\partial(D^{22}+D^{12})/\partial R=L(c+d)+k(-b+e) \tag{3.3}$$

The effect on profits of firm 2 is

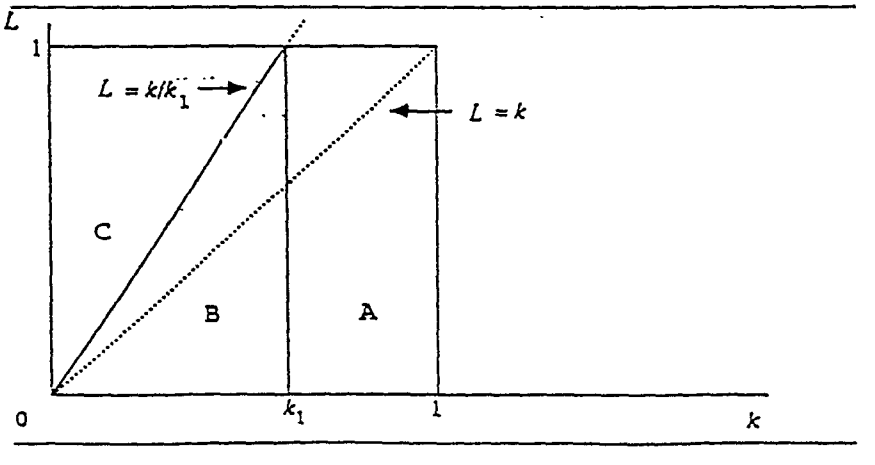
$$\partial\pi^2/\partial R=(p_2+q_2)[L(c+d)+k(-b+e)] \tag{3.4}$$

Firm 2 will choose compatibility as long as $\partial\pi^2/\partial R<0$ or, equivalently,

$$k/L>(c+d)/(b-e)\equiv k_1 \tag{3.5}$$

Clearly, the resulting degree of compatibility depends on the relative size of k and L. Note that, since $L\leq 1$, compatibility will be chosen by firm 2 whenever compatibility is chosen by firm 1, as well as in other cases. Figure 3.2 shows the regions of values of k and L that result in full compatibility, partial incompatibility, and total incompatibility. For $k>k_1$ (region A) both firms choose compatibility. For $L>k/k_1$ and $k<k_1$, region B, firm 2 chooses compatibility while firm 1 chooses incompatibility. For $L<k/k_1$, region C, both firms choose incompatibility. If the size of the demand within the small private network is equal to or smaller than the size of the demands for hybrid transactions—that is, if $L\leq k$, at least the small demand network chooses compatibility. In Figure 3.2, note that the line $L=k$ lies in regions A and B and never in region C, where both firms choose incompatibility.

Figure 3.2
Compatibility for Different Relative Demands for Hybrids



THEOREM 3: *Both firms choose compatibility when the demand for hybrids is large. For smaller demand for hybrids, both firms choose incompatibility provided that the demand for A_2B_2 is sufficiently high. If demand for hybrids is small and demand for A_2B_2 is sufficiently low, firm 2 chooses compatibility while firm 1 chooses incompatibility.*

The important message of Theorem 3 is that the worst case for compatibility is when the demand for hybrids is small. Small demands for hybrids tend to drive the market toward incompatibility. However, this drive is weakened when there is a disparity in the single-producer demand as well. Thus, compatibility tends to arise more often, and incompatibilities when they arise are smaller, when only one single-producer system has large demand. The individual incentives of firms to create a shared network are weak when the demand for services across components of different networks is weak. However, weak demand for services of one of the private networks tends to drive that particular network toward compatibility with the strong network. This desire is, in general, not reciprocated by the network with large demand.

BUNDLING OF SERVICES

Often, complementary services are "bundled" and offered at a discount if purchased together from the same firm. For example, a bank can offer free ATM service at its own ATMs. Bundling is, of course, an imperfect form of price discrimination. The bundled good is offered at a price that does not exceed the sum of the prices of its components when offered separately. Let good A_1B_1, the combined banking and ATM services of firm 1, be offered at price s_1 while separately these services are offered at q_1 and p_1 as before. For consumers to buy the bundled good rather than its individual components, it must be that $s_1 \leq p_1 + q_1$. Similarly, let good A_2B_2 be offered as a bundle at price s_2. Again it is required that $s_2 \leq p_2 + q_2$.[8] The hybrids still require adapters. Thus the cost of A_1B_2 is $p_1 + q_2 + R$ and the cost of A_2B_1 is $q_1 + p_2 + R$. See Table 3.2.

Table 3.2
Composite Goods and Corresponding Prices with "Mixed" Bundling

Composite Good	Price
A_1B_1	s_1
A_1B_2	$p_1 + q_2 + R$
A_2B_1	$q_1 + p_2 + R$
A_2B_2	s_2

The profits of firm 1 are

$$\pi^1 = s_1 D^{11} + p_1 D^{12} + q_1 D^{21}$$

Consider the incentive for compatibility in the case of symmetric demand above under Assumptions 1–3.

$$\partial\pi^1/\partial R = s_1(c+d) + (p_1+q_1)(-b+e) \leq (p_1+q_1)(-b+c+d+e) < 0$$

The incentive for compatibility is stronger when bundling is allowed. Thus we have

COROLLARY 3: *Provided that the demand for transactions across the two private networks is equal in size to the demand for transactions within each private network, a private network that bundles within-the-private-network transactions (and sells them at a price below the sum of the prices of their components) will choose full compatibility.*

ASYMMETRIC ADAPTERS

So far it has been assumed that the same adapter is required to make systems A_1B_2 and A_2B_1 functional. It is possible, although unlikely, that different adapters are required for systems A_1B_2 and A_2B_1. Let them be of cost R_{12} and R_{21} respectively. The demand functions for the four composite goods are now

$$\begin{aligned}
D^{11} &= D^{11}(p_1+q_1,\ p_1+q_2+R_{12},\ q_1+p_2+R_{21},\ p_2+q_2)\\
D^{12} &= D^{12}(p_1+q_2+R_{12},\ p_1+q_1,\ p_2+q_2,\ p_2+q_1+R_{21})\\
D^{21} &= D^{21}(p_2+q_1+R_{21},\ p_2+q_2,\ p_1+q_1,\ p_1+q_2+R_{12})\\
D^{22} &= D^{22}(p_2+q_2,\ p_2+q_1+R_{21},\ p_1+q_2+R_{12},\ p_1+q_1)
\end{aligned}$$

The effect of an increase in R_{12}, the cost of the adapter required for system A_1B_2 on the profits of firm 1, is

$$\partial\pi^1/\partial R_{12} = p_1(-b+c) + q_1(c+e)$$

Under conditions of symmetric substitution between ATM services and banking services—that is, $c=d$—and using the symmetry of demand system implied by Assumption 1, $p_1=q_1$, I can write

$$\partial\pi^1/\partial R_{12} = p_1(-b+c+d+e) < 0$$

which is negative by Assumption 2. All firms then choose full compatibility for all products (transactions). If the degree of substitutability between ATM

services differs from the degree of substitutability between banking services, $c \neq d$, it is possible that a firm will decide to introduce incompatibilities for some transactions, as $d\pi^1/dR_{12}$ can be positive. However, note that it is impossible that a firm will desire to create incompatibilities for *both* products A_1B_2 and A_2B_1. This is because the effect on profits of an increase in both R_{12} and R_{21} is the same as the effect of an increase in R, the cost of the common adapter. It was established above that firms want to minimize R. Therefore, a firm cannot desire to maximize both R_{12} and R_{21}. If it decides to introduce some incompatibilities it will be only in one of the two hybrids.

SEQUENTIAL DECISIONS

Up to this point, the choices of design specifications (that imply the degree of compatibility) and prices were considered simultaneously. This means that the firms had the same degree of flexibility in varying prices and design specifications. This may be the case in some industries. In others, it may well be that design specifications are much less flexible in the short run than prices. Such a situation is best modelled as a game of two stages. In the first stage, firms choose design specifications and the degree of compatibility of their elementary goods is implied by them. In the second stage firms choose prices. The first stage is interpreted as the long run and the second stage as the short run. In choosing design specifications, firms anticipate the effects of their decisions on prices that are chosen later. To be precise, suppose that firms 1 and 2 have chosen x and y as their parts of the cost of the adapter. Then in the second stage, the equilibrium prices depend on x and y (the degree of compatibility) and therefore can be written as $p_1^*(x,y)$, $p_2^*(x,y)$, $q_1^*(x,y)$, $q_2^*(x,y)$. In the first stage, in choosing prices, firms anticipate the effects of their choices (x,y) on the equilibrium prices. Thus, the profit function of the first stage for firm 1 is

$$\pi^{1d}(x,y) = \pi^1(x,y,\ p_1^*(x,y),\ p_2^*(x,y),\ q_1^*(x,y),\ q_2^*(x,y)\ ),$$

where the superscript "d" denotes the stage of choice of design specifications.

When firm 1 contemplates an increase in the part of the cost of the adapter it controls, x, there are two effects on profits. One is the direct effect, $\partial\pi^1/\partial x<0$, which is the same as in the games of simultaneous choices that we have seen before in the section on the symmetric case. The second effect of changes in x is through prices. It is

$$\partial\pi^1/\partial p_1 \cdot \partial p_1^*/\partial x + \partial\pi^1/\partial q_1 \cdot \partial q_1^*/\partial x + \partial\pi^1/\partial p_2 \cdot \partial p_2^*/\partial x + \partial\pi^1/\partial q_2 \cdot \partial q_2^*/\partial x$$

The first two terms of this equation are zero from the profit maximization of the last stage. Thus it simplifies to

$$\partial\pi^1/\partial p_2 \cdot \partial p_2^*/\partial x + \partial\pi^1/\partial q_2 \cdot \partial q_2^*/\partial x \tag{3.6}$$

Thus, the difference between the simultaneous and the two-stage games in the individual firm's incentive to reduce the price of the adapter is proportional to the cross-price effect on profits, $\partial\pi^1/\partial p_2$, and to the influence of the price of the adapter on the opponent's price, $\partial p_2^*/\partial x$. For symmetric demand, it is shown in Economides (1989b) that the cross-price effects on profits are positive, $\partial\pi^1/\partial p_2>0$, $\partial\pi^1/\partial q_2>0$, and that an increase in the price of the adapter decreases the prices of the opponent, $\partial p_2^*/\partial x<0$, $\partial q_2^*/\partial x<0$. Therefore the second-stage effect described in equation (3.6) is negative. Firms have greater incentives to reduce the price of the adapter in a two-stage framework than in the simultaneous framework. For asymmetric demand, Economides (1989b) shows for a two-stage framework similar results to the ones in section 5.

CONCLUSION

This chapter has demonstrated that when the demand for transactions across private networks is as large as the demand for transactions within the private networks, each private network has an incentive to establish compatibility with other private networks and facilitate hybrid (across networks) transactions. However, when demand for transactions across networks is low, each private network chooses to be incompatible and to restrict access from outside. The result is maximum possible incompatibility of the two private networks. When the demand for transactions within only one of the two private networks is high, this network chooses to maximize incompatibilities, while the other private network desires compatibility. The result is partial incompatibility of the two private networks.

These results show the significance of the relative scale of the demand for transactions within and across private networks for the decision of compatibility and for the emergence of a shared network. The best scenario for the emergence of a shared network is one of equal demands for all four types of transactions, within each private network and across them. The worse scenario for the emergence of a shared network is when the demand for transactions across the private networks is small. However, the incentive for incompatibility is *weakened* when there is disparity in the demands for transactions within each private network as well. Incompatibilities will occur less often and will be smaller when the demand for transactions within one of the private networks significantly exceeds the demand for transactions within the other network than when the demands within private networks are equal.

NOTES

I thank Paul David for many helpful remarks and extensive discussion and the participants of the Annenberg Conference on Electronic Services Networks and of the Tech-

nology and Productivity Workshop at Stanford University for their helpful suggestions. Special thanks to co-editor Steve Wildman for extensive editorial suggestions.

1. In practice, there are more than two elementary goods in each cash withdrawal done through an ATM. Transactions are routed through a network switch that connects ATMs and banks.

2. Of course, the fact that latecomers have individual incentives to attach themselves to old specifications does not necessarily mean that these old specifications are the optimal in the advanced technological environment. For example, nearly all typewriters come with the QWERTY keyboard, so identified by the positioning of the keys in the upper left hand side. The positioning of the keys in the QWERTY keyboard was efficient at the time of its introduction. Since typewriters of the time jammed frequently, it was necessary to force typists to type more slowly. This was accomplished by the awkward positioning of keys in the QWERTY keyboard. Current models of typewriters can easily accommodate even the fastest typist. Although inefficient, the QWERTY keyboard is still virtually ubiquitous because of the large pool of typists that have been trained to use it and because of the keyboard retooling cost. See Paul David (1986, 1987).

3. The crucial assumption relevant to the discussion of this chapter is the assumption of equal demand for hybrids and single-producer goods. As seen in later sections of this chapter, the relaxation of this assumption can lead to equilibria of incompatible components and separate networks inaccessible from the outside.

4. Here it is assumed that firms do not offer discounts for their single-producer goods. The case when such discounts are offered is discussed under "bundling" in the sixth section.

5. There is nothing lost by the assumption of additive and non-negative contributions by each firm to the cost of the adapter. If technology is such that the incompatibility introduced by one firm can be wiped out by the opponent (so that one firm can force full compatibility), any equilibrium of the present model where at least one firm chooses compatibility will be mapped to a full compatibility equilibrium in the model of the new technology. If the technology is such that one firm can force total incompatibility, then any equilibrium of the present model where at least one firm chooses incompatibility will be mapped to a total incompatibility equilibrium.

6. If adapters were produced and sold by the component-producing firms the problem would revert to the standard problem of price discrimination.

7. This setup is equivalent to nonzero marginal costs with p_i and q_i interpreted as the differences of prices above marginal costs.

8. In the terminology of Adams and Yellen (1976), this is "mixed bundling" since the individual components are available as well as the bundle.