

LYNN O. WILSON, ALLEN M. WEISS, and GEORGE JOHN*

The authors examine the bundling options of a firm that sells a multicomponent industrial system. A system is described by individual component attributes and by its "integration" and its "modularity." Customers have heterogeneous preferences. Competing firms offer components that can be mixed and matched with the firm's components if it unbundles. If new systems added by unbundling are more modular or have a superior component, the market may grow. Growth is the key to making the unbundling option attractive.

Unbundling of Industrial Systems

Industrial systems typically consist of many components. Computer systems are made up of computer hardware (e.g., monitor, CPU, disk drive, keyboard), operating and applications software, and a network that enables many computers to be hooked together. Communications systems, such as an airline reservation system or a banking transactions network, also require several components. For example, telephone networks consist of both transmission and switching equipment. To assemble circuit boards, PC manufacturers generally use separate machines to mount, solder, and test the devices on the boards. In each instance, for these systems to be operational, more than one component must be purchased. Hence, a customer's purchase decision is made at the system level rather than at the component level. In many cases a "turnkey" system can be acquired that is pre-engineered, predesigned, and complete in all its components. However, most industrial systems are technologically divisible. That is, the system can be divided into distinct components (e.g., computer hardware and the applications software) and these components can be sold separately. To the degree that there are open standards for the interfaces between the various components, the system components can be sold by multiple vendors. Customers then can assemble components from various vendors into their own system.

Generally, suppliers of such equipment follow different strategies; some sell complete systems and others sell components. Observations of industry evolution reveal that unbundling becomes more popular over time (e.g., Jackson 1985; Porter 1985). Porter identifies two inter-related managerial decisions that face incumbent systems suppliers. An incumbent systems supplier may decide to maintain its position as a systems vendor and strengthen its comparative advantages by using proprietary technology to offer customers more integrated system benefits. Alternatively, it may choose to unbundle complete systems and to sell components separately. In the latter case, it has the added option of possibly withdrawing from the market for one or more of the components constituting the system and relying on other firms to supply the market needs for those components. As Porter puts it, a firm ". . . must decide whether it should supply the . . . products or allow outside suppliers to provide some of them" (p. 417). Despite the pervasiveness of these strategic issues, he notes that they commonly have been overlooked.

Each of the alternative courses of action carries certain benefits and some risk. For example, bundled systems can deliver enhanced performance by allowing for a package of optimized components incorporating proprietary interfaces or "firmware." Nontechnological customer benefits of the bundled approach include a single point of purchase and after-sale service. However, maintaining a bundled approach can be risky. For example, as customers become more knowledgeable, aspects of bundled systems such as "one-stop shopping" become less attractive. Also, bundled systems may not appeal to customers with idiosyncratic needs. Customers that need a particular component to perform at a higher level may be able to obtain it only by mixing and matching com-

*Lynn O. Wilson is Distinguished Member of Technical Staff, AT&T Bell Laboratories. Allen M. Weiss is Assistant Professor of Marketing, Graduate School of Business, Stanford University. George John is Associate Professor of Marketing, Carlson School of Management, University of Minnesota.

The order of the authors' names is arbitrary. Each author contributed substantially to the article.

ponents from a variety of suppliers. Such customers are vulnerable to competitive inroads.

In sum, neither strategy is clearly dominant. It would be desirable to identify the conditions that make each option attractive. Though the literature has examined the bundling issue, it is of limited applicability to industrial systems. The work has been motivated mainly by anti-trust issues and the models that have been formulated examine bundling as a price discrimination device (e.g., Adams and Yellen 1976; Long 1984; Schmalensee 1984). The issues involving industrial systems, with their interdependent components, are largely left unresolved. A model addressing those issues would generate managerial insights and enable us to verify the validity of suggestions that have been offered in the descriptive literature.

We present a model that examines the options and identifies the conditions that make bundling of industrial systems attractive. We model a situation in which a firm currently selling a complete system is competing with specialist firms selling individual components that customers can mix and match to form complete systems. The firm's options in the model are (1) to continue selling a bundled system, (2) to unbundle and sell the system's components individually alongside the bundled system itself, and (3) to sell components only and possibly withdraw from selling one or more of those components.

Our model is motivated by Hauser and Shugan's (1983) approach to modeling defensive marketing strategies. Unlike DEFENDER, however, it is used to generate qualitative insight in the form of decision heuristics, rather than to calculate quantitative results (market share, profits, etc.). We characterize buyers as having heterogeneous preferences for the attributes of competing multicomponent systems. The size of the market depends on the levels of the attributes of the competing systems. Our explanation for unbundling is derived fundamentally from the tension between the benefits afforded by an integrated system and those afforded by mixing and matching components.

We show that the growth in the size of the market resulting from unbundling is a crucial determinant of the attractiveness of the strategy. Several managerial heuristics are presented. We also account for stylized facts about bundling. For instance, as industries mature, our model shows that unbundling becomes more likely because of the interfirm diffusion of technology and the evolution of standards.

We first briefly review the relevant literature and then describe customer decision making. A market model is described in which customers are distributed in a preference space, and the positions of the customers in this space and the levels of the attributes of the industrial systems together determine the customers' choices. Sales volumes and profits then are introduced. Next, we develop a general criterion for unbundling and present our fundamental results. We describe the consequences over time as technologies diffuse and standards evolve in an

industry. Finally, the implications for research and practice in marketing are discussed.

LITERATURE REVIEW

The types of questions addressed in our research are similar to those examined in the economic literature on product bundling. The earliest models in that literature were formulated to understand the rationale for block booking (requiring customers to purchase a bundle of substitute products, such as movies, from a single vendor) and tie-in sales (requiring customers to purchase a commodity used with a focal product, such as paper with mimeograph equipment, from a single vendor). As such activities were conjectured to extend monopoly power and erect barriers to entry, they were believed to have important antitrust and policy implications. Researchers demonstrated that these bundling techniques act as a subtle form of price discrimination by sorting customers into groups with different reservation prices. For examples of this line of research, see Burstein (1960) and Stigler (1968).

Several studies within the price discrimination tradition have provided a more detailed analysis of the conditions for bundling to be an optimal strategy. In their classic analysis, Adams and Yellen (1976) examine the profitability of commodity bundling by a two-product monopolist when the products are independent in demand for all customers. Three general types of bundling options are specified: unbundled sales (the two products are priced and sold separately), pure bundling (the two products are sold only as a bundle), and mixed bundling (both the bundle and the individual products are sold). Adams and Yellen demonstrate that different rankings of the three strategies are possible, depending on the level of costs associated with supplying the goods and the distribution of customers in reservation price space. They show that some form of bundling is generally more profitable than maintaining a policy of unbundled sales.

By assuming a specific distribution on demand (i.e., Gaussian demand) in the Adams and Yellen framework, Schmalensee (1984) shows that mixed bundling is, in general, a more profitable strategy than either pure bundled or unbundled sales. His result depends on the correlation between reservation prices for the two products that constitute the bundle. Likewise, Philips (1981) shows that mixed bundling tends to lead to higher sales than does a pure bundled or unbundled sales strategy.

A few authors have extended the demand structure used in the preceding models. For example, Long (1984) considers the case in which the firm's products are complements. However, his results are inconclusive for the relative profitability of the various bundling strategies. Dansby and Conrad (1984) examine the case in which the bundling process itself may provide additional value beyond the combined value of the individual components. Alternatively, if the bundle contains an unwanted component, the bundling process may be value-reducing. They show that the relative profitability of bundling depends on both the extent to which the bundling process

is valued and the previously cited distribution of reservation prices for the components.

Hanson and Martin (1990) examine the issue of bundle pricing. They provide a practical method for a single firm, facing segmented customer demand and product-specific costs, to determine how to bundle the products in its line and to find the optimal prices for the bundles. They point out that economies of scope also can be a profitable basis for bundling.

The stream of work reviewed leaves certain issues unaddressed. First, is there a demand-side rationale for bundling products for sale other than for price discrimination purposes? Is it possible that bundled multicomponent systems may be more appealing to some customers? Unfortunately, the presumptive benefits of bundling (or unbundling) products are not identified explicitly. Customers are described simply in traditional economics fashion by the reservation prices. From a managerial standpoint, this approach leaves one unable to derive reasonable heuristics for action. For example, how should a bundled systems supplier react when faced with competition from specialist suppliers of components? What aspects of multicomponent systems must be examined to assess the value of retaining a bundled sales strategy? The extant results also are not capable of explaining stylized facts of interest such as the observation that unbundling typically becomes a more popular strategy as industries mature (Jackson 1985; Porter 1985).

In a related set of literature on product standards, Farrell and Saloner (1985) and Katz and Shapiro (1985) provide models in which firms decide whether to produce compatible goods. Because compatibility is needed in order to mix and match unbundled components from different manufacturers, we might expect this literature to provide some insight. Unfortunately, as Matutes and Regibeau (1988) demonstrate, much of this work does not translate well into our research context because firms are modeled as producing a single good in contrast to the multicomponent systems at issue here. In extending this work, Matutes and Regibeau offer a model in which each of two firms sell both components of a two-component system that are either compatible or incompatible with the other firm's offering.

In a two-firm, two-stage game, the firms first decide whether to make their components compatible and then compete on prices. The decision to produce compatible components is analogous to a firm unbundling and selling components individually, thus enabling customers to mix and match. Assuming a uniform distribution of customers and an all-or-nothing type of compatibility, Matutes and Regibeau show that the perfect Nash equilibrium of this game involves producing compatible products only when standardization can be enforced unilaterally by *either* party (i.e., by building an adapter). If compatibility requires the agreement of *both* parties, there are two equilibria in pure strategies (compatible and incompatible).

These results are interesting, but leave some managerial issues unresolved. For example, the authors do not

offer actionable recommendations about the desirability of unbundling (or bundling). We address such matters directly. Further, their assumptions of all-or-nothing compatibility and a uniform distribution of customer preference seem unduly restrictive. Relaxing these assumptions would allow an assessment of a broader range of situations of interest. In particular, the all-or-nothing notion of compatibility is plainly counterfactual.

Despite the importance of the issue to marketers, only one article in marketing has addressed bundling. Guiltinan (1987) discusses price bundling with complementary consumer services. He begins with a firm selling a set of items, some or all of which might be bundled into a package. He compares the profitability of two kinds of mixed bundling with that of unbundling, while ignoring pure bundling. Presumably because of his context (consumer services), he argues that ". . . we are not concerned with tie-in sales (pure bundling)." Thus, Guiltinan's work complements the central focus of our study, in which firms currently marketing bundled systems face specialist suppliers of components. This focus requires us to compare pure bundling with unbundling.¹

Our model addresses issues that are addressed inadequately in the literature. We offer an explanation for bundling that relies on identifying aspects of bundled and unbundled multicomponent systems that appeal to customers. Rather than relying on price discrimination as an explanation, this model posits that bundling is motivated by the profitability of offering these desired benefits to the customer.

MODEL DEVELOPMENT

Industrial systems purchases are complex organizational decisions encompassing a multitude of variables (see Webster and Wind 1972 and Anderson and Chambers 1985 for comprehensive models of organizational purchases). Though models of an optimal bundling strategy ultimately may reflect the total richness of the firm's decision-making environment, we deliberately use a minimum of parameters to capture the essential features of the situation while retaining analytical tractability. Obviously, a system can consist of many individual components; at a minimum, we have two components. We allow N components to be combined ($N \geq 2$). We refer to them as components 1, . . . , N . For example, a computer system might be thought of as a combination of a processor, monitor, keyboard, printer, operating system, and applications software.

Multicomponent System Attributes

Traditionally, marketers have conceptualized a given product as consisting of a bundle of attributes, and we use this approach to characterize industrial systems comprising more than one divisible product or component. However, when applying this framework at the level of

¹We are grateful to an anonymous *JMR* reviewer for pointing out these contrasts with the Guiltinan article.

a system, rather than at the level of the individual components, one can identify attributes that describe the individual components and other attributes that vary at the level of the overall system. In the example of a computer system, CPU speed is an attribute of the processor, resolution is an attribute of the monitor, and a system maintenance arrangement is an attribute more closely identified with the system as a whole. The importance of each of these attributes naturally varies across customers.

We assume that multicomponent systems can be described along (1) attributes that describe individual components of a system and (2) two system-level attributes, the integration and the modularity of the system.

Components of the system. We assume that the system consists of N components where $N \geq 2$. Each component is described by a positively valued attribute: $\alpha_1, \alpha_2, \dots, \alpha_N$. Increases in each of these α_i 's describe higher quality or better performing components from the customer's perspective. Though it is possible to describe each component itself along a set of attributes, we use a single attribute to describe each component to preserve analytical tractability. One can think of this single attribute as a summary measure for the relevant set of attributes for that component.

System integration. This system-level attribute is defined as the degree to which the customer perceives that the multicomponent system has been optimized from a systems perspective. This attribute is described by α_{N+1} . We consider integration as a continuous attribute, ranging from a minimal level of functionality to the case in which the system has been seamlessly integrated. System-level integration arises in many ways and offers several benefits to customers.

Technologically, one means of enhancing the perception of integration is to offer a "turnkey" system whose components have been pre-engineered and designed to work together. Often, a manufacturer can build a "turnkey" system to deliver better performance by incorporating proprietary interfaces between the components of the system. For example, a microcomputer system's processor (the CPU) can draw screen images on a monitor much faster by using machine-specific instructions that by relying on the corresponding instructions built into a more portable operating system. One also can optimize the system by designing each part of it to take into account the strengths and weaknesses of other parts. For example, in designing a turnkey process control system, one can choose to use relatively less "intelligent" (cheaper) transducers if the central unit is designed accordingly.

Perceived system integration also is enhanced by offering single-source responsibility for system maintenance and training, the practice of solution selling, and giving customers the opportunity for "one-stop shopping." With single-source responsibility, customers need not diagnose problems themselves and then call the supplier of the component or subsystem that has broken down.

Solution selling assures customers prior to purchase that the setup will work "right out of the box" without much "tweaking." One-stop shopping reduces the cost of "qualifying" suppliers; a single qualification effort suffices for the entire system and the customer avoids having to qualify individual component suppliers separately.

That system integration is desired by the marketplace is evident from the existence of firms specializing in enhancing this attribute of industrial systems. Resellers that combine components from different manufacturers into a package to meet some end users' needs more fully and support the end user are basically following a strategy of providing an enhanced level of the integration attribute. In fact, they are termed "systems integrators" in the industry.

That the importance attached to this attribute should vary across customers is also readily observed. For example, one-stop shopping is less valuable to more knowledgeable customers. Similarly, a turnkey system is not as attractive to customers with more idiosyncratic needs because the firm selling a turnkey system must choose some "average" or typical systems-user profile around which to optimize system performance. A customer with idiosyncratic needs may require one of the system components to perform at a much higher level than that offered by the turnkey system. For example, a mainframe computer system optimized for scientific computing may be too slow for "transaction processing" involving many simple requests, such as an airline reservations system. These reasons often are cited as the factors that enabled minicomputer firms such as Digital Equipment Corporation to challenge IBM's turnkey systems approach in the early days of the minicomputer market by targeting more knowledgeable and sophisticated customers and enabling them to customize systems from unbundled components.

System modularity. Modularity is defined as the perceived degree to which a system conforms to open standards. It is modeled by the parameter α_{N+2} . Like integration, modularity is a continuous attribute, and the actual amount of the attribute present is a function of the scope of the available standards (*de facto* or official) as well as the degree to which they are followed. In some markets, most of the interfaces between system components are defined in proprietary ways, thus making for low system modularity. This situation is common in emerging industries where a number of proprietary standards may be competing with each other. In other situations, a comprehensive set of standards is available, but is adhered to only partially by product offerings. For example, the V.32 standard for high speed modems was established by an official standards organization (CCITT) and constitutes a very comprehensive set of specifications. Nevertheless, many manufacturers of high speed modems bypass the standard to varying degrees. They use proprietary "tricks" to achieve the desired performance more cheaply than is possible by adhering to the full V.32 standards.

Modularity is valued by customers because when the interfaces between system components conform more closely to open standards, customers are better able to interconnect multiple vendor equipment and thereby mix and match system components more effectively. This capability enables customers to address their specialized needs more effectively. In addition, it enables customers to react to future changes more readily because of the lower switching costs associated with more modular systems. The major role of switching costs in industrial markets has been noted by several researchers. For example, Jackson (1985) notes that a customer purchasing a less modular system becomes more dependent on the original vendor for follow-on purchases and, incidentally, on the prices charged for those purchases. The reason is that a firm cannot switch out of a nonmodular system easily. Only a wholesale transfer is possible, and the costs of such a transfer can be exorbitant. These arguments about the benefits of modularity are consistent with work on organizational behavior (e.g., Pfeffer and Salancik 1978) and vendor-buyer relations (e.g. Heide and John 1987) showing that firms will consciously avoid dependence whenever possible.

The importance attached to modularity by customers varies greatly. For example, we have noted that customers with unusual needs are likely to place a premium on being able to choose components that meet their needs well. Likewise, it is reasonable to assume that firms making purchases critical to their organization are highly motivated to reduce potential dependence. This situation is illustrated by the practice of "second-sourcing" in the semiconductor industry, where a firm that sells a component with a proprietary interface, such as a microprocessor, often licenses other firms to produce and sell that item. This practice is remarkable as it effectively ends the focal firm's monopoly on the item. Notice that once a customer has purchased a system using a particular microprocessor, it faces heavy switching costs to replace this critical item. Hence it would be reluctant to commit to using the item unless it could reduce its dependence on the focal firm that originally developed it. Second-sourcing arrangements ensure that the hitherto proprietary component is in effect a *de facto* standard item available from multiple sources.

Another interesting feature of modularity is that the evolution of a hitherto proprietary set of standards into a *de facto* open standard might increase the modularity of a system with that set of standards. For example, when the IBM PC was introduced, it was a low modularity system that incorporated a proprietary "bus" architecture and a new operating system, neither of which adhered to current microcomputer standards such as the S-100 "bus" or the CP/M operating system. Yet, as the IBM PC evolved to a *de facto* standard, the presence of other products adhering to this standard raised the modularity of the original product itself. As we show subsequently, this spillover effect has important implications for explaining certain stylized facts about bundling.

Integration-modularity tradeoffs. One might conclude from the preceding discussion that the two system attributes are not independent of each other in the sense that systems with high modularity are necessarily systems with low integration, and vice versa. This conclusion is not correct. Consider Table 1, which provides examples of systems that may have high and low degrees of integration and modularity. Here, a supplier offering a turnkey system with maintenance contracts and solution selling while adhering to open standards is providing a system that is high on both integration and modularity. The mixed and matched system from different vendors is high on modularity but low in integration because it lacks the systemwide maintenance features. The cell with low levels of both attributes describes a situation in which a firm offers a set of components that do not conform to a comprehensive set of standards, thus allowing for only a minimal level of system integration. Typically, this situation arises when several different proprietary standards have evolved within one firm and the connectivity between them is crude. Last, a turnkey system designed and optimized with proprietary interfaces exemplifies a condition of low modularity and high integration.

Attribute comparisons of bundled versus unbundled systems. One can expect that bundled systems offer a higher level of the integration attribute than systems put together by mixing and matching different suppliers' components. As described previously, such systems can use proprietary interfaces to integrate components seamlessly, as well as to offer features such as one-source responsibility that enhance the level of this attribute.

In contrast, we would expect bundled systems to be perceived as being less modular than mixed and matched components from different suppliers. This perception would hold even if the bundled system ostensibly adhered to open standards, because a firm selling a bundled system is perceived to be more likely to use proprietary interfaces to some degree to enhance performance. As one would suspect, these differences in integration and

Table 1
EXAMPLES OF SYSTEMS WITH VARIOUS COMBINATIONS
OF INTEGRATION AND MODULARITY

Modularity	Integration	
	High	Low
High	Turnkey system with the benefits of open standards	Mixed and matched system from different vendors: no single-source responsibility, no one-stop shopping, etc.
Low	Turnkey system with proprietary interfaces	Mixed and matched system from one firm's components with minimal standards

modularity between bundled and unbundled systems are crucial in assessing the optimality of the decision to bundle.

Model of Customer Behavior

To begin, suppose our focal firm sells two or more component products, such as a computer and operating software, which it markets as a complete system. Other firms also are present in the market and some of them sell unbundled components. Hence customers have the option to acquire a system in different ways—they can purchase components as a complete system from one source or individually from various firms for assembly. Actually, a reseller might be the “source” of a complete system put together from different manufacturers, but we do not maintain this distinction. We call the outcome of the s^{th} way to purchase a system of components system s . Suppose that there are S systems.

Let $\alpha_{1s}, \alpha_{2s}, \dots, \alpha_{Ns}$ be the levels of the attributes of components 1, \dots , N of system s . Let α_{N+1s} describe the level of the integration attribute of system s and let α_{N+2s} characterize the level of the modularity attribute of system s . Associate with system s the attribute vector $\alpha_s = (\alpha_{1s}, \alpha_{2s}, \dots, \alpha_{N+2s})$. Customers are assumed to have homogeneous perceptions about the values of these attributes. However, the relative importance of each attribute α_{is} varies across customers. For customer k , this importance “weight” of the i^{th} attribute is denoted by γ_{ik} . Enumerate the customers, $k = 1, \dots, K$, and associate with customer k the preference vector $\gamma_k = (\gamma_{1k}, \gamma_{2k}, \dots, \gamma_{N+2k})$. In contrast with the extant work in the field, we do *not* assume any particular distribution for these preference vectors γ_k .

Customer valuation of system s . Customer k , given different possible combinations of attributes for integration, modularity, and the components, calculates an overall value for system s according to some function $U(\alpha_s, \gamma_k)$. The qualitative results do not depend on any particular specification of U . However, we assume a specific functional form in the Appendices to demonstrate some numerical examples.

Customer choice. To model the customer’s choice process, we use a choice rule that yields the customer the greatest net surplus. Given a price P_s for system s , customer k will be willing to buy it if

$$(1) \quad U(\alpha_s, \gamma_k) - P_s \geq 0.$$

That is, a customer will purchase a system only if the value for the system is greater than the price.

Given a choice between system s and system t offered at prices P_s and P_t , customer k will prefer system s if

$$(2) \quad U(\alpha_s, \gamma_k) - P_s \geq U(\alpha_t, \gamma_k) - P_t.$$

As with the customer value function, our qualitative results are robust to the functional form of the choice rule. For example, another choice rule such as $U(\alpha_s, \gamma_k)/P_s \geq 1$ that maximizes utility per dollar rather than net surplus would yield the same qualitative results.

Notice that this model allows for a no-purchase decision. Hence, the total market size is not fixed, in contrast with the DEFENDER model of Hauser and Shugan (1983). The actual market size depends on the attribute levels and prices of all the systems that are available to customers. The possibility of changes in market volume turns out to be a crucial element in determining the profitability of the bundling decision.

SALES VOLUMES AND PROFITS

Here, we define the market sets and sales volumes associated with each system in the market. These definitions are needed to assess the profitability of the bundling decision.

Market Sets and Sales Volumes

Customers’ preference vectors lie within a *preference space*. The *market set* μ_s associated with system s is the region within the preference space defined by

$$(3) \quad \mu_s = \{\gamma | U(\alpha_s, \gamma) - P_s \geq 0 \text{ and}$$

$$U(\alpha_s, \gamma) - P_s \geq U(\alpha_t, \gamma) - P_t, \text{ for } t \neq s, t = 1, \dots, S\}.$$

If $\gamma_k \in \mu_s$, then by equations 1 and 2, customer k is willing to purchase system s and prefers it to all other systems. The *sales volume* v_s of system s is the number of customers whose preference vectors γ_k are within the market set μ_s :

$$(4) \quad v_s = |\mu_s| \equiv \{\text{Num } k | \gamma_k \in \mu_s\}.$$

Notice that the market set and sales volume for *each* system depend on the attribute vectors and prices of *all* the systems. Intuitively, these notions have a geometric interpretation. The preference space is a pyramid ($N = 2$) or a higher dimensional generalization of a pyramid ($N > 2$). Customers’ preference vectors are within the pyramid. Each vertex has an attribute associated with it. The more important a customer considers an attribute to be, the closer the preference vector is to the associated vertex. If only *one* system is available, the market set for that system consists of a region within the preference pyramid bounded on one side by a surface, the *system surface*. If *two or more* systems are available, any two market sets have at most a surface in common, the *indifference surface*. In general, the market set for a system is in a region bounded by indifference surfaces with adjoining market sets, by faces of the pyramid, and by a system surface. These concepts are illustrated in Appendix A.²

Profits for the Focal Firm

Because firms can possibly profit from the sales of individual components as well as sales of complete sys-

²If the utility function specified in Appendix A is used, the geometric representation is particularly simple: the system surface is a plane. Furthermore, if the choice rule involves maximizing utility per dollar with the division criterion, the indifference surfaces are also planes.

tems, we introduce some terminology. Suppose the focal firm, henceforth called firm 1, supplies system 1, which is bundled, and possibly supplies components to other systems. Let

$$(5) \quad \chi_{is} = \begin{cases} 1 & \text{if firm 1 supplies component } i \text{ to system } s, \\ 0 & \text{otherwise.} \end{cases}$$

Let p_i be the price firm 1 charges for component i and c_i be its unit cost. P_1 is the price of system 1; let C_1 be its cost. We do not assume any specific relationship between the sums of the prices (costs) for the components and the price (cost) of the system. However, we do assume implicitly throughout our discussions that system sales are profitable, $P_1 - C_1 > 0$. The total profit Π that firm 1 realizes from system sales and component sales is

$$(6) \quad \Pi = (P_1 - C_1)v_1 + \sum_{s=2}^S v_s \sum_{i=1}^N \chi_{is}(p_i - c_i).$$

THE UNBUNDLING DECISION: A NORMATIVE CRITERION

To begin, consider the position of the focal firm. It currently sells a bundled system, and other firms are in the market selling complete systems and/or components. From the vantage point of the customer, S systems are available, some of them bundled and others mixed and matched from various firms' offerings. The choice facing the focal firm is either to continue to offer the bundled system or to unbundle the components and offer them for sale along with the bundled system.³

We compare profit of the focal firm for the bundled case (labeled with a superscript b) with that for the unbundled scenario (labeled with a superscript u). When the focal firm's system remains bundled, S^b systems can be formed from the product offerings of the various firms in the market. If the firm unbundles, $S^u > S^b$ systems can be formed because the focal firm's unbundled components can be mixed and matched with components from other firms to form additional systems. The net effect of unbundling is to increase the number of systems available to the customer. As before, system 1 is the focal firm's bundled system.

A Criterion for Unbundling

Assume the focal firm's system prices and costs are the same with or without unbundling.⁴ If any fixed costs incurred during unbundling are ignored, unbundling is

profitable for the focal firm if $\Pi^b < \Pi^u$ or, by equation 6, if

$$(7) \quad (P_1 - C_1)v_1^b < (P_1 - C_1)v_1^u + \sum_{s=S^b+1}^{S^u} v_s \sum_{i=1}^N \chi_{is}(p_i - c_i).$$

Because the sales volumes depend on the attributes and prices of all systems available, they, too, must be labeled with superscripts b or u . The term on the left and the first term on the right refer to the profit for firm 1 from *system* sales under bundling and unbundling, respectively. Note that the bundled system is still available even when unbundled components are offered for sale. The second term on the right refers to profit for firm 1 from (unbundled) *component* sales.

Inspecting equation 7, we can see that whether unbundling is profitable depends on the relative margins of the system and of the various components and on the relative sales volumes. By equations 3 and 4, the sales volumes, in turn, depend on the customer preference distribution γ_{ik} , $k = 1, \dots, K$, and on the value functions $U_s^b - P_s$, $s = 1, \dots, S^b$ and $U_s^u - P_s$, $s = 1, \dots, S^u$. One might expect *systems* profit for firm 1 to be lowered by unbundling because there are more systems against which the original system must compete. In contrast, profit from *component* sales increases and may compensate for the loss in system profit. It is this tradeoff that we must explore in greater detail to obtain managerially useful insight. A reformulation of equation 7 into market segments is useful in this effort.

We divide some market sets into disjoint subsets. In the notation σ_s^p used for these subsets, the subscript s refers to system s and the superscript p takes some mnemonic values.

First we split the market sets μ_1^b and μ_1^u into some disjoint subsets. Recall that μ_1^b is the market set for the focal firm's system (system 1) when it is sold only as a *bundled* system and μ_1^u is the market set for the same system when the firm also sells the individual components *unbundled*. Let σ_1^l represent the region in preference space that can contain preference vectors of customers who are *loyal* to system 1; they will purchase system 1 whether or not firm 1 unbundles. Let σ_s^c represent the region for those customers who would purchase system 1 if firm 1 does not unbundle but who are *captured* by system s if firm 1 unbundles ($s = S^b + 1, \dots, S^u$). These other systems will contain components from the focal firm. Let σ_1^g be the region for *growth* (if any) in the market for system 1 possibly due to the enhanced perception of modularity of this system resulting from firm 1's unbundling.⁵ Then σ_1^l , σ_1^g , and all the σ_s^c are mutually disjoint and satisfy

³Firm 1, after unbundling, might offer only selected components and not offer the bundled system. Though this case is not modeled explicitly here, the modifications needed to do so should be evident.

⁴The model can be extended to incorporate endogenous changes in the margins of the systems. The method is similar to that presented, but the details of implementation are considerably more complicated. We do not introduce game theoretic concepts; the model has enough complexity and is sufficiently rich in new insight as it is.

⁵If externality effects are present, the unbundling of system 1 may increase the modularity of the other original systems ($s = 2, \dots, S^b$) as well as that of system 1. Conceivably, some of these original systems may benefit from such large increases in modularity that they capture some market from system 1. We consider this outcome to be unlikely and assume it does not occur.

$$(8) \quad \mu_1^b = \sigma_1' \cup \left(\bigcup_{s=S^b+1}^{S^u} \sigma_s^c \right), \quad \mu_1^u = \sigma_1' \cup \sigma_1^g,$$

where $\sigma_1' = \mu_1^b \cap \mu_1^u$.

Next, let μ_s^u represent the market set for system s when the focal firm unbundles its product. For $s = S^b + 1, \dots, S^u$, split the market sets μ_s^u into disjoint subsets corresponding to *capture* and *growth*: σ_s^c is the region of preference space that can contain the vectors of customers captured from system 1 by system s and σ_s^g is the region for customers purchasing system s and representing growth in the total market. Then

$$(9) \quad \mu_s^u = \sigma_s^c \cup \sigma_s^g \quad \text{for } s = S^b + 1, \dots, S^u.$$

These subsets can be defined analytically in terms of the $U(\alpha_s, \gamma)$ and P_s in a manner analogous to equation 3.

To show this analysis more concretely, we calculated the market sets and subsets for a case in which system 1 is unbundled and its component 1 is combined with a component 2 from another supplier to form a second system, system 2. This numerical example appears in Appendix A.

Returning to the unbundling criterion, and using analogous notation for the sales volumes defined by sums of the preference distribution over the appropriate market sets (cf. equation 4), we have from equations 8 and 9

$$(10) \quad v_1^b = v_1' + \sum_{s=S^b+1}^{S^u} v_s, \quad v_1^u = v_1' + v_1^g, \quad v_s^u = v_s + v_s^g$$

for $s = S^b + 1, \dots, S^u$.

Equations 7 and 10 yield the general criterion: *unbundle if*

$$(11) \quad \sum_{s=S^b+1}^{S^u} v_s \left[(P_1 - C_1) - \sum_{i=1}^N \chi_{is}(p_i - c_i) \right] < v_1^g(P_1 - C_1) + \sum_{i=1}^N (p_i - c_i) \sum_{s=S^b+1}^{S^u} \chi_{is} v_s^g.$$

By exploring equation 11 in greater detail, we can pinpoint circumstances that favor unbundling and vice versa. To begin, observe that the loyal customers play no part in the criterion. Their contributions to firm 1's profit remain the same whether or not it unbundles, and are of no consequence. One must concentrate instead on the customers who will be lost to competing systems and on those who will be gained through component sales or possibly through growth in systems sales.

Cases Favoring Unbundling

Larger unit margins from unbundling. Suppose the sum of the per-unit margins for components that firm 1 contributes to each system are large in comparison with the bundled system margin:

$$(12) \quad (P_1 - C_1) < \sum_{i=1}^N \chi_{is}(p_i - c_i)$$

for $s = S^b + 1, \dots, S^u$.

Result: Firm 1 should unbundle.

According to this simple decision rule, unbundling is favored regardless of the levels of bundled and unbundled sales whenever the per-unit margin for the bundled system is less than the sum of any combinations of per-unit margins of unbundled components used in a system. For decision-making, one need not know the sales volumes involved, only the unit margins. These values are more readily available to a firm than are the prospective sales volumes that might be realized from systems and components if it were to unbundle.

When might one expect such per-unit margins for the components to be greater than the per-unit margin for the bundled system? As an example, suppose there is precisely one additional system ($S^u = 2$) made available with unbundling and the presence of a supplier for one component (say component 2). Then $\chi_{12} = 1$ and $\chi_{22} = 0$. Unbundling is profitable if $P_1 - C_1 < p_1 - c_1$, that is, if the margin for the system is less than that for component 1. One such situation is when component 2 is being "subsidized"⁶ by component 1 in the bundled system.

The result suggests that in addition to unbundling the system, the firm should exit the component markets being cross-subsidized (e.g., component 2). In emerging markets, firms often initially offer bundled systems in which some component cross-subsidizes another component because of the unavailability of alternative sources for the subsidized component. This lack of other sources may be due to the unwillingness of other firms to commit to building suitable components until they are reasonably sure of the size of the market. As the market matures and alternative sources become available, our result shows that it makes sense for the focal firm to unbundle its system and exit the component markets for which its margin is relatively small or negative.

Market growth from unbundling. The s^{th} term in the summation of the left side of equation 11 represents the amount by which system s (formed by unbundling) cuts into the profit of the bundled system because of *capture* of customers. Unless there is cross-subsidization, each such term is typically positive. On the right side of equation 11, the first term represents additional profit for firm 1 due to *growth* in the market for system 1 because of unbundling. Such growth might come from externality effects. The i^{th} term in the summation on the right side represents the profit from sales of component i that is due to *growth* in the total systems market.

What one needs to assess, then, is the size of margins, differential margins, and associated sales volumes. The smaller the differential margins $(P_1 - C_1) - \sum_{i=1}^N \chi_{is}(p_i - c_i)$ are in markets with appreciable captured sales vol-

⁶Strictly, "subsidization" is not defined when the system is sold only as a bundled system. The negative margin is revealed only when the system is unbundled.

umes v_s^c , and the larger the component margins $p_i - c_i$ are in markets with appreciable growth affecting firm 1 $\sum_{s=S^*}^{S^*+1} \chi_{is} v_s^g$, the more attractive unbundling will be.

Result: All else being equal, more growth in sales volume from unbundling makes the option more attractive to the firm.

The obvious question is: When and why will growth occur as a consequence of unbundling? To find the answer, we use the following result.

Theorem 1: Suppose system 1 has a nonempty market set μ_1 and system 2 is added to the market (because firm 1 has unbundled system 1). If it is priced the same as system 1 and if the values of its attributes are identical to those of system 1 except that it is superior on one attribute ($\alpha_{i2} > \alpha_{i1}$) and inferior on another ($\alpha_{j2} < \alpha_{j1}$), then $\sigma_1^i \neq \emptyset$ and $\sigma_2^j \neq \emptyset$. If μ_1 does not occupy all of preference space, then $\sigma_2^j \neq \emptyset$.

Proof: The proof of theorem 1 is tedious, but straightforward. It involves writing the definitions of the market subsets in set theoretic notation and exhibiting points in preference space belonging to each of the subsets. Several different cases must be examined, depending on the ordering of the attribute values α_{is} . We omit the details.

The theorem shows that when one additional system (system 2) is made available because the focal firm chooses to unbundle, system 1 retains some of its market and loses the rest to the added system, but the total potential market grows. *Potential* growth will occur as long as the additional system is superior on some attribute, even if it is inferior on other attributes. By equation 4, *actual* market growth (measured in terms of sales volumes) will occur whenever there are customers whose preference vectors are in the growth set. In what situations might additional systems be superior? The answer provides the key to using this result for making managerial decisions.

First, the new systems created by unbundling are unlikely to be superior on the *integration* attribute. We have already seen that proprietary interfaces, one-stop shopping, and other features tend to endow a bundled system with a higher level of system integration. These new systems are thus likely to be inferior on this attribute. Hence, growth is not going to occur because of added integration being provided by the additional systems created with unbundling.

Second, as each component is described by an attribute that captures its performance or quality level, the potential growth resulting from a *superior component* is easy to understand. For example, suppose a specialist firm develops a component that is superior to the corresponding one bundled with the system. If the focal firm unbundles, new customers who need higher performance can be attracted to buy an unbundled system with the new component. In many markets, the presence of specialist suppliers offering higher performing components

than those contained in the extant bundled system creates growth in the overall market.

Third, even without superior components being offered by other firms, unbundling *per se* can result in growth as it enhances the *modularity* attribute. Recall that mixed and matched systems from multiple sources (like system 2 in Table 1) will be perceived as having greater modularity than a bundled product like system 1. The new system will appeal to customers who value modularity because it reduces their prospective switching costs. This effect is consistent with the history of several markets in which growth accelerated when standards emerged that enabled firms to mix and match components. Conversely, growth often is stifled because of the lack of standards despite technological improvements, as is the case currently in the market for local area network (LAN) equipment.

The presence of other firms offering components that are not technically superior can nevertheless potentially increase the focal firm's profits if it capitalizes on the situation by unbundling. This point is often overlooked by managers who view such "clones" as merely capturing their sales. Such components help the overall market to grow by establishing the focal firm's system as the *de facto* standard.

New market segment from unbundling. The preceding results show that growth from superior modularity or superior components could prompt a decision to unbundle. We turn here to the effects of market segments. If the new systems that are made available under unbundling are purchased only by customers who did not buy the previously bundled system from the focal firm, then $v_s^c = 0$. In effect, the new systems made possible by unbundling attract only a hitherto untapped market.

Result: Firm 1 should unbundle.⁷

What industry circumstances would lead to this result? It occurs when the added systems made possible with unbundling are so different from the focal system in a component or in modularity that they appeal to entirely new customers who were not reached by the original system *and* when the preferences of the customers who selected the unbundled system 1 are clustered in a region of preference space not captured by the added systems. Figure A1 in Appendix A is a numerical example. Here, the customers who prefer system 1 (triangles) are clustered away from customers who prefer system 2 (diamonds). In general, $\sigma_s^c \neq \emptyset$ (cf. theorem 1). However, it is possible to have $v_s^c \equiv |\sigma_s^c| = 0$ if system 1 is designed to appeal to customers whose preferences are in another part of its market set.

A good example of this type of growth is the use of Apple Macintosh components by another firm to offer a

⁷To be precise, one needs some minimal growth, but it is virtually guaranteed by the enhanced modularity, if not by superior components, of the new systems made available.

lighter, more portable version with a flat screen. The Macintosh is not designed as a true portable computer (industry observers call it a "luggable" machine) and hence many of its components are heavy and bulky. The portable system (the Dynamac) combines the read-only memory chips and the operating system from the Macintosh with other lighter, more compact components (e.g., the box and screen). The resulting system is considerably more expensive than the original Macintosh and is clearly aimed at a segment of the market that values the lighter components highly enough to warrant purchasing it. Industry observers do not expect it to cut into sales of the original system at all. It is interesting to note that Apple chose *not* to unbundle its system to sell the necessary components to the other firm. Consequently, the firm was forced to buy whole Macintoshes and literally cut open the cases to remove the read-only memory chips and other parts to build the new system. Our normative model suggests that the optimal decision for Apple would have been to unbundle its system to supply this firm with the necessary components, barring other factors such as its intention to offer a similar product in the future.

Inferior but cheaper systems from unbundling. Unbundling makes sense when the added systems offer prospective customers sufficient superiority on component attributes or system modularity. What if the added systems are not superior on any dimension, but are priced lower?

Theorem 2: Suppose the focal firm's bundled system (system 1) has a nonempty market set and that an additional system (system 2) becomes available. If the values of the attributes of system 2 are identical to those of system 1 except that it is possibly inferior in one attribute ($\alpha_{2i} \leq \alpha_{1i}$) and if it is priced lower than system 1, then $\sigma_2^c \neq \emptyset$. If μ_1 does not occupy all of the preference space, then $\sigma_2^s \neq \emptyset$. If the price P_2 is sufficiently small ($P_2 = \min_i \alpha_{2i}$), then $\sigma_1^c = \emptyset$.

Proof: The method of proof is similar to that for theorem 1. We omit the details.

Result: If the new systems are much cheaper, firm 1 should unbundle.

The new system can drive the focal system out of the market even if it is not superior on any attribute, provided it is priced low enough. What industry circumstances might lead to such an outcome? This result is consistent with the observation from several real-world markets that when lower priced systems can be put together from unbundled components, the higher priced bundled systems lose large shares even when they offer superior levels of attributes. The computer-aided design and manufacturing (CAD/CAM) market and the word processor market both exhibited such a pattern of large volume losses for expensive bundled systems when cheaper systems were made possible by matching unbundled software with standard hardware. Typically these mixed and matched systems did not offer as high a level of performance as the bundled systems. Their main at-

traction was their considerably lower price, which was made possible by the sales of large volumes of standardized products. In these circumstances, firm 1 can only hope to salvage some profits by participating in component sales.

Cases Favoring Bundling

Having explored equation 11 to pinpoint circumstances that favor unbundling, we see that growth in sales volume from unbundling favors that decision. Now let us examine cases for which staying bundled is more attractive. As one might suspect, there is no growth in these situations that a firm can capitalize on by unbundling.

Dominated systems from unbundling; no growth. If system 1 dominates any additional systems made possible by its unbundling in the sense that no customers are captured and there is no market growth ($v_s^c = 0$, $v_1^c = 0$, $v_s^e = 0$), both sides of equation 11 vanish.

Result: Firm 1 should not unbundle.

When a focal firm is confronted with the choice of unbundling its hitherto bundled system, it should not do so when its own bundled offering is superior to the added systems—for example, when all of the system's attribute levels are at least as great as those of the new systems and its price is no more than those of the new systems. Consider a focal firm currently selling a bundled system that adheres closely to open standards (the upper left cell in Table 1). Suppose other firms are selling components that are not technically superior to those in the bundled system. As system 1 is already high on the modularity attribute by virtue of the open standards, any additional systems made possible by unbundling system 1 would not offer any advantages on this attribute. Furthermore, we know that the added systems are not likely to be superior in integration. System 1 is dominant if the systems are priced identically; the firm should not unbundle.

In short, a firm that has already adopted open standards and is pricing its product competitively should not unbundle unless superior components offered by other firms allow for the possibility of market growth. This is an important result as it indicates that even if the firm faces competition from plug-compatible components, it need not accommodate them by opening up its systems market. This result is consistent with Sun Microsystem's approach of adhering closely to open standards, but selling complete bundled systems.

Smaller unit margins from unbundling; no growth. In the case just discussed, there is no loss of system sales to the additional systems made available with unbundling. More typically, we would expect some loss in system sales to these new systems. Suppose now that such capture occurs, but that the added systems offer no growth in the total sales volume: $v_s^c = 0$ for $s = S^b + 1, \dots, S^u$ because the new systems offer neither superior modularity nor superior components. Suppose also that

$$(13) \quad P_1 - C_1 > \sum_{i=1}^N \chi_{is}(p_i - c_i)$$

for $s = S^b + 1, \dots, S^u$.

Then equation 11 is not satisfied.

Result: Firm 1 should not unbundle.

The main difference between this setting and the previous one is that here the focal system is *not* dominant. By unbundling, the focal firm is simply trading systems sales for component sales. When competition among suppliers leads to lower unit margins for components, the focal firm is better off retaining its bundled system. This result reinforces the insight that unbundling is not favored unless the presence of better components from other firms or better modularity creates market growth.

INDUSTRY EVOLUTION AND UNBUNDLING

Accounts of industry evolution (e.g. Porter 1985) often note that unbundling tends to become more common over time. Observers attribute the unbundling to several influences, including the evolution of formal or *de facto* standards (see, e.g., Besen and Johnson 1986 for a discussion of standards and the broadcasting industry) and the diffusion of hitherto proprietary technology into the products of several firms. We rely on a numerical demonstration to make the argument that diffusion of technology and evolution of standards can account for this pattern. We show that if diffusion and standardization cause the attributes of the systems to change with time, it is appropriate for a firm to decide to keep a certain system bundled at one time and to unbundle it at a later time.

How do diffusion and standardization act over time to affect the attributes of competing systems? Porter (1985) suggests that firms typically initially develop products that embody proprietary knowledge. Over time, these proprietary technologies diffuse through an industry via several mechanisms. For example, firms learn about each other's technologies through physical inspection of competitors' products (i.e., reverse engineering), personnel transfers, and discussions with outside suppliers and distributors. Consequently, diffusion tends to reduce differences in component quality over time.

In addition to this effect, proprietary technologies that are inherently incompatible compete for survival as industries mature. The evolution of formal or *de facto* standards resolves this incompatibility by providing a common basis for product design. Thus evolution of standards tends to reduce modularity differences between competing systems. Let us now formalize these notions.

Assumptions

Suppose customers' preferences remain constant over time and prices do not change. Let the attribute levels α_{is} and the ratios $\beta_{i,su} \equiv \alpha_{is}/\alpha_{iu}$ derived from them be functions of time. As argued before, the $\alpha_{is}(t)$ and $\beta_{i,su}(t)$

change because of diffusion and standardization. Let us consider these changes for each type of attribute.

Component attributes. Suppose diffusion mechanisms operate to allow competitors to catch up with the industry leader. We define the industry leader for component i at time t_1 to be the firm that supplies component i to system v where $\alpha_{iv}(t_1) = \max_s \alpha_{is}(t_1)$. Assume the industry leader does not alter its product: $\alpha_{iv}(t) = \text{constant}$. Furthermore, assume that for all s , $d\alpha_{is}(t)/dt \geq 0$ and $\alpha_{is}(t) \rightarrow \alpha_{iv}$ as t becomes large, that is, technologies improve and eventually catch up with that of the leader. Then no component can maintain a significant advantage indefinitely: for any s and u , $\beta_{i,su}(t) \rightarrow 1$ as t becomes large.

Integration. Assume firm 1, the focal firm, is the early industry leader for integration and $\alpha_{N+11}(t) = \text{constant}$. Assume $d\alpha_{N+1s}(t)/dt \geq 0$, that is, the level of integration of any system competing with that provided by the focal firm improves with time, and $\alpha_{N+1s}(t) \rightarrow \alpha_{N+11}$ as t becomes large. Then $\beta_{N+1,1s}(t) > 1$ is monotone decreasing. Thus, the perceived advantage of system 1 in integration diminishes with time. Furthermore, assume all $\beta_{N+1, su}(t) \rightarrow 1$ as t becomes large.

Modularity. Assume $d\alpha_{N+2s}(t)/dt \geq 0$: standards evolve and externalities increase. For systems S_s and S_u , s and $u \neq 1$, assume $\beta_{N+2, su}(t) \rightarrow 1$ as t becomes large: all such systems evolve to a single open standard. Assume $\beta_{N+2, 1s}(t) < 1$: system 1 has a relative disadvantage in modularity. If system 1 remains bundled, $\beta_{N+2, 1s}(t) = \text{constant}$; in contrast, if firm 1 unbundles system 1, $\beta_{N+2, 1s}(t)$ is monotone increasing and will tend to unity as t becomes large.

Market Outcomes Over Time

The focal firm has two options: to keep system 1 bundled or to unbundle it.

Option: keep the system bundled. Suppose the focal firm keeps system 1 bundled, maintaining a proprietary interface. Then system 1 has a (diminishing) advantage in integration issues and a (growing) disadvantage in modularity issues. If prices remain constant, the entire market grows, but the focal firm does not take part in the growth at all. In fact, its market erodes. Appendix B illustrates this situation with a numerical example.

Option: unbundle. We observe in the preceding section that one of the main motivations for unbundling is to take advantage of market growth. We show that unbundling will help reduce the erosion of system 1's market and will also open up the possibility of the focal firm's participating in component markets. Appendix B illustrates this situation also with a numerical example.

Discussion. The choices for the focal firm, then, appear to be either to retain a bundled system and have its market erode or to unbundle by adopting standard interfaces. By unbundling, the firm will have a potentially larger market. The latter appears to be more attractive. This result is consistent with the observation that systems tend to become unbundled over time.

One other important aspect of the evolution of the market also must be considered. As we illustrate in Appendix B, one advantage of a bundled system is that small price changes typically create only small changes in sales volume. Hence, the firm faces a relatively stable market, albeit a shrinking one. In contrast, Appendix B shows that with unbundling, small changes in prices can create large changes in sales volumes. Hence, the firm faces a relatively more volatile market, albeit a potentially larger one. This tradeoff between stability and volatility may induce smaller, more risk-averse firms to choose to retain a bundled system longer than other firms.

CONCLUSIONS

We examine the bundling decision facing a firm that sells a multicomponent system and offer an understanding of the unbundling decision beyond the price discrimination mechanism discussed in the extant literature. We focus on a firm that currently sells its system only in a bundled form, and ask when it might be more profitable to unbundle the system and possibly even withdraw some of the components. Our article complements the only other article in marketing on this general topic (Guilinan 1987), which compares several different bundling options for service firms but does not include an appraisal of the bundle versus unbundle decision.

To accomplish such an appraisal, we develop a model incorporating several characteristics of markets for multicomponent industrial systems. We characterize systems along attributes describing the individual components and two system-level attributes, the integration of the system components and the modularity of those components. Bundled systems are endowed with superior integration whereas unbundled systems offer greater modularity. Customers are assumed to have heterogeneous preferences for all of the attributes. Competitors are present that can provide the individual components for customers to mix and match. In this setup, a decision by the focal firm to unbundle results in the creation of new systems being added to the set of systems currently available to the customer. The firm's customers divide into three segments as a result. Some of them remain with the focal system (the loyal group), others are captured by other systems (the captured group), and a third set are attracted into the market (the growth group). By comparing the sizes of these groups before and after unbundling, we derive a general criterion for when a profit-maximizing firm should unbundle its system and sell the components individually, or even possibly stop selling some of the components. By analyzing the general criterion, we obtain a set of managerially useful heuristics.

These qualitative insights can be summarized in the following way. A simple decision rule is to compare the per-unit margin of the bundled system with the various unit margins of the unbundled components; unbundle if the former is smaller. If the margin rule does not signal unbundling, an appraisal of the added systems' attributes in comparison with the focal system's attributes is needed. Several different heuristics emerge from this appraisal.

When the added systems offer increasingly greater superiority on some component or else better modularity, unbundling is increasingly favored because it results in a larger market. The growth comes from customers who were unwilling to purchase the original bundled system but who are willing to purchase components from that firm to mix and match with other firms' components. This type of growth unbundling is particularly appealing when it attracts hitherto untapped customer segments.

In contrast, when the added systems offer no superiority along the relevant attributes, retaining a bundled system is generally more profitable. Two specific cases are noted. First, if the focal system's components are superior to other firms' components and the system already adheres closely to open standards, its dominance would result in no growth from unbundling. The focal firm should not unbundle simply to accommodate "clone" component firms. Second, even when the focal firm's system is not dominant, it should not unbundle in a no-growth environment as it would simply be trading system sales for lower-margin component sales.

We note one important exception to the general preference for retaining a bundled system when the added systems are not superior in either components or modularity. When these added systems are markedly cheaper, we show that their price advantage could drive the focal bundled system out of the market. Unbundling would enable the focal firm to salvage some profits by participating in the component market.

Finally, our model accounts for the observed phenomenon that unbundled systems tend to become more common over time. We show that in a market with diffusion of technology and evolution of open standards, the choice of a firm is either to retain a bundled system and lose volume or to unbundle and participate in a larger market. However, by unbundling the firm will face a more volatile market.

Limitations

Perhaps the greatest limitation of the model is that it does not address the strategic interaction between firms. Notice that in some markets, an incumbent monopolist firm may be in a position to increase the minimum scale of entry by refusing to unbundle its multicomponent system. A prospective entrant would have to introduce a full system rather than a single component. In our model, we assume that the focal firm already coexists with other systems and component firms. Entry already has occurred and cannot be undone. Hence, when entry is a relevant concern and the focal firm views bundling as a weapon to forestall entry, our model is not very useful. A game theoretic approach is needed to cover such circumstances. We trust that future work will focus on this matter.

Managerial Implications

What do our findings mean to a manager? Though we might simply point to the heuristics, we offer some observations on how these results can be used in a more

sophisticated way. We begin with a look at certain aspects of the methodology. An analytic model is used to obtain the heuristics. The only empirical evidence consists of examples from industry accounts. Two questions arise here. First, is an analytic model needed to provide this insight to managers? Second, must we wait for systematic empirical validation before advocating the use of the heuristics to assist in decision making?

The first question is readily answered. An analytic model is not warranted for its own sake; rather, it enables one to sharpen the internal validity of the results and to disclose gaps in the reasoning. Without the analytic model, we would not be able to show the critical importance of growth in sales volume resulting from the added systems created by unbundling. The results obtained from examining the tradeoffs between capture, growth, and loyalty are simply not amenable to verbal reasoning. Some of the results are also counterintuitive and require the logical consistency afforded by the model to make them acceptable. For example, the unit margin comparison rule ignores the seemingly important differences in sales volume with and without bundling. The analysis shows that we can safely ignore the prospective sales volumes and rely only on the unit margins. In sum, the insights provided here are not easily obtained without a formal analysis.

Turning to the question of systematic empirical evidence, we hope future research will focus on providing empirical tests. Nevertheless, the circumstances surrounding the issues at hand are such that empirical work will be very difficult for several reasons. For example, obtaining data on sufficient numbers of unbundling decisions as a basis for statistical testing is probably a very difficult undertaking. By definition, the decision is made only once for a system. Furthermore, the model is a normative one and valid data on the prospective sales and costs needed to assess the model are not readily obtained from accounting records or questionnaires. An alternative approach would be to assess whether firms practice the qualitative recommendations of the model. For example, do industries exhibit more unbundling over time? This approach is an indirect test of the normative model as competitive pressures are assumed to be sufficient in a Darwinian sense to make firms "grope" toward normatively correct decisions. Notice that our anecdotal observations of industry practice are a (very?) weak form of this type of test. It helps to establish the model's usefulness in the absence of more systematic data, but it does not in any way substitute for systematic empirical work. The difficulties suggest that it may be counterproductive to suspend judgment until systematic empirical evidence is available. The analytic, normative model with its internally consistent logic can be useful if managers are sensitive to their own decision contexts.

In particular, managers should be aware of the degree to which their own decision contexts are within the applicable domain of the model. When issues or variables outside the scope of the model dominate the bundling decision facing a particular firm, the heuristics lose their

value. Two specific limiting conditions can be identified. First, the results are not very useful when the focal firm is in a position to affect the probability of entry by other firms by virtue of its decision to unbundle. The model is relevant if component firms already are present in the market and entry deterrence is no longer an issue. Another limiting condition is the broad scope of the model. It is not a decision support system that uses data collected for a specific situation, and hence is not very useful in fine-tuning decisions within the overall decision to unbundle. For example, a firm may decide to promote certain components in a package even after unbundling. Alternatively, a firm may offer a volume purchase discount aggregated over a range of components. Such decisions require data on the precise levels of attributes and the importance weights attached to them by customers. Extending the model into a decision support system that can utilize such data is possible, but requires development of a measurement methodology. We hope future research will focus on such an extension. Meanwhile, the heuristics we offer are useful as long as decision makers are sensitive to the two limiting conditions.

APPENDIX A

We give examples of market sets and sales volumes, and show how the loyal, captured, and growth sets can be represented.

Customer Value Function

We use a Cobb-Douglas function for the numerical calculations because it (1) exhibits interdependencies among the components that are characteristic of system purchases, (2) has attractive properties, such as proper convexity, and (3) is tractable. The value of system s to customer k can be written as

$$(A1) \quad U(\alpha_s, \gamma_k) = \prod_{i=1}^{N+2} \alpha_{is}^{\gamma_{ik}},$$

where:

$$(A2) \quad \sum_{i=1}^{N+2} \gamma_{ik} = 1, \quad 0 \leq \gamma_{ik} \leq 1.$$

System Planes

The choice rule (with equality) $U(\alpha_s, \gamma_k) - P_s = 0$ describes a plane (or hyperplane if $N > 2$) in the preference space. If vertices i and j are associated with attributes i and j respectively, the system plane intersects the edge between the two vertices a fraction

$$\ln(\alpha_{is}/P_s) / \ln(\alpha_{is}/\alpha_{js})$$

of the distance between vertex i and vertex j . The plane need not intersect the pyramid at all: markets sets consisting of the entire pyramid ($P_s < \min_i \alpha_{is}$) or of none of the pyramid ($P_s > \max_i \alpha_{is}$) are possible. If the plane intersects the pyramid, the market set μ_s is given by the region on the side of the plane containing the vertex as-

sociated with the attribute α_{is} with the highest value. If the price of the system changes, the system plane moves normal to itself. A lower price increases the size of the market set within the pyramid.

Indifference Surfaces

If two or more systems are available, any two market sets have at a surface in common, the *indifference surface*. The choice rule $U(\alpha_s, \gamma_k) - P_s = U(\alpha_i, \gamma_k) - P_i$ (with equality) defines an indifference surface in preference space. This surface can be approximated by a plane (or hyperplane if $N > 2$) whose edge intersections are given by

$$\ln[(\alpha_{is}/\alpha_{ii})/(P_s/P_i)]/\ln [(\alpha_{is}/\alpha_{ii})/(\alpha_{js}/\alpha_{ji})]$$

in a manner analogous to that above. The formula is exact if $P_s = P_i$, or if the choice rule involves maximizing utility per dollar with the division criterion rather than maximizing net surplus with the subtraction criterion.

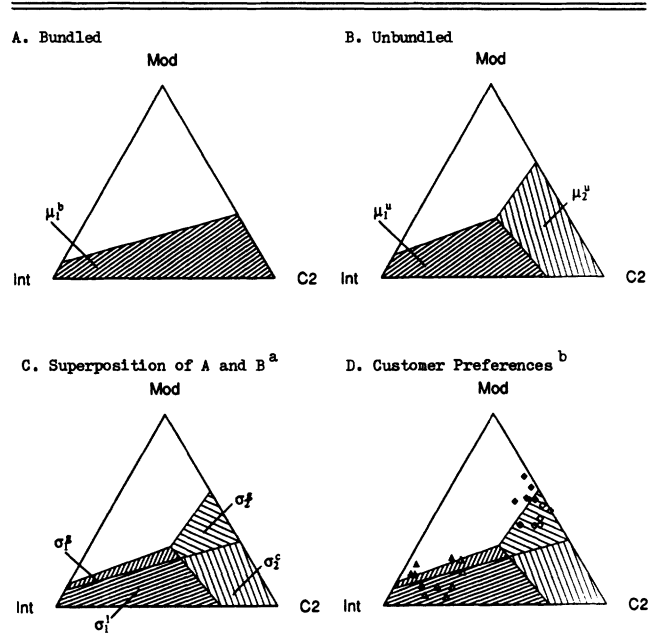
At equal prices, the market sets are convex polyhedra (or their higher dimensional generalizations for $N > 2$). If a price changes, the affected indifference surfaces and the system plane move (nearly) normal to themselves in such a way that the size of the market set for a system increases if its price is reduced.

Calculating Sales Volumes

Using the tools developed above, we can illustrate how attribute levels of systems, customer preferences, and prices are used to calculate sales volumes for each system. We use the attribute valuations and prices given in Table A1. Figure A1 shows the market sets and subsets for a case in which system 1 is unbundled and its component 1 is combined with a component 2 from another supplier to form a second system, system 2. For ease of presentation only, we have taken customers with $\gamma_{ik} = 0$ so that their preference vectors are on the face of the preference pyramid opposite the vertex corresponding to the component 1 attribute. The vertices pictured correspond to the component 2, integration, and modularity attributes. In the calculations we use the Cobb-Douglas valuation function and net value choice rules described previously.

Notice that customers remaining loyal to system 1 are those for whom the benefits of integration are *relatively*

Figure A1
ONE FACE OF PREFERENCE PYRAMID SHOWING MARKET SETS FOR THE SYSTEMS



*To show the loyal, captured, and growth sets.
^bWhite: customers who purchase some system. Black: customers who do not purchase any system. Triangles: customers who prefer system 1 to system 2. Diamonds: customers who prefer system 2 to system 1.

important in comparison with the benefits of modularity and of component 2. Customers captured by system 2 are those for whom both the original system 1 and the new system 2 have acceptable levels of all attributes, but to whom the benefits of modularity and/or of component 2 are relatively more important. Growth in the market occurs through customers to whom the benefits of the bundled system 1 are insufficient to make them willing to purchase it, but to whom the enhanced benefits of one or the other system are enough to make them change their minds. These results are specific to the particular values assumed for the calculation. Of greater interest are more generalizable outcomes discussed in the text.

APPENDIX B

We give numerical examples to illustrate the concepts of market outcomes over time that are discussed in the text.

Option: Keep a Bundled System

Suppose there are two systems, system 1 and system 2. Let the attribute levels and prices for system 1 remain constant at the values indicated in Table B1. Let those for system 2 take the values indicated in Table B1 at times $t_1, t_2,$ and t_3 (with $t_1 < t_2 < t_3$). Thus system 2 is

Table A1
ATTRIBUTE VALUATIONS AND PRICES OF A BUNDLED SYSTEM AND TWO UNBUNDLED SYSTEMS

	Bundled		Unbundled	
	System 1	System 1	System 1	System 2
α_1 (component 1)	—	—	—	—
α_2 (component 2)	2.5	2.5	2.5	2.7
α_3 (integration)	2.0	2.0	2.0	1.6
α_4 (modularity)	1.1	1.3	1.3	1.5
P (price)	1.9	1.9	1.9	1.9

Table B1
ATTRIBUTE VALUATIONS AND PRICES OF TWO SYSTEMS
AT VARIOUS TIMES

	System 1		System 2		
	All t	t_1	t_2	t_3	
α_1 (component 1)	2.3	2.4	2.4	2.4	2.4
α_2 (component 2)	2.5	2.5	2.5	2.5	2.5
α_3 (integration)	2.0	1.5	1.7	1.9	1.9
α_4 (modularity)	1.3	1.5	1.6	1.7	1.7
P (price)	1.9	1.9	1.9	1.9	1.9

inferior, but improving, in integration; it is superior, and improving further, in modularity. In the example, the attribute level of component 1 is slightly superior in system 2 to that in system 1. The resulting market sets are illustrated in Figure B1.

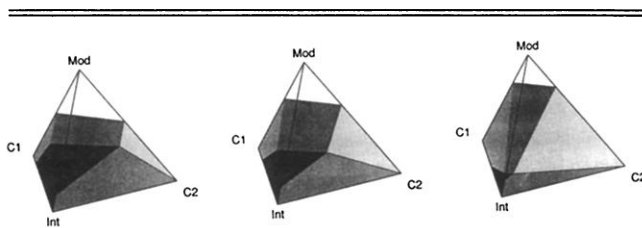
The market set $\mu_1(t)$ for system 1 diminishes with time, because system 2 captures an increasingly large market subset $\sigma_2^c(t)$ and because there is no growth ($\sigma_1^c(t) = \emptyset$). In contrast, the market set $\mu_2(t)$ for system 2 increases both because of increasing capture $\sigma_2^c(t)$ from system 1 and because the growth subset $\sigma_2^g(t)$ increases with time. Keeping system 1 bundled does not appear to be an attractive long-range alternative for firm 1. How long it may remain a feasible alternative depends on equation 11. One must assess where the customers are positioned within the preference space and how long a significant advantage in integration can be maintained.

Option: Unbundle

Suppose the focal firm unbundles system 1 at time t_3 (cf. Table B1). Four possible systems can be formed: system 1 with increased modularity for the reasons discussed previously, system 2 as before (at time t_3), and two additional systems, system 3 and system 4, created by mixing components from the first two systems. Suppose the attribute values and prices associated with these systems are as indicated in Table B2.

The values of α_{1s} and α_{2s} are determined by appro-

Figure B1
MARKET SETS μ_1 (LOWER REGION) AND μ_2 (UPPER REGION) FOR SYSTEM 1 AND SYSTEM 2 AT TIMES $t_1, t_2,$ AND t_3^a



^aSystem 1 stays bundled; the levels of integration and modularity of system 2 improve with time.

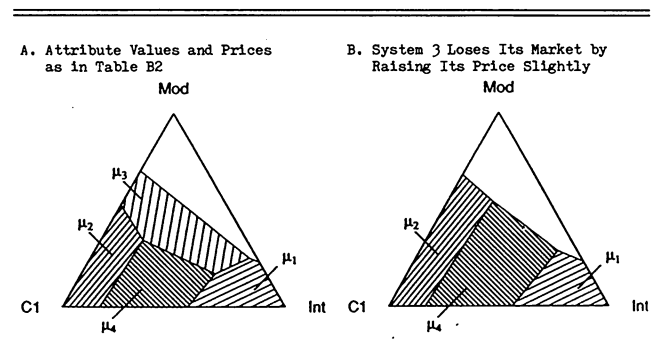
appropriate mixing of components. The values of the integration parameter α_{3s} are such that system 1 has the highest level, but the others are close. The values of the modularity parameter α_{4s} are such that the modularity of system 1, now offered with a standard interface, is greater than it was previously, but is still slightly below that of the other systems because there would be a perception that system 1 is less modular. The prices of the systems are nearly equal; attribute values and prices are chosen so that each system has a nonempty market set μ_s .

For ease of presentation, we show only the intersection of the resulting market sets with the leftmost face of the preference pyramid in Figure B2. The indifference surfaces (curves) are very nearly planar (linear). The central thing to observe in part A of Figure B2 is the large potential growth in system and component markets for the focal firm; it sells system 1 to a larger market than it did before unbundling (cf. part C of Figure B1) because its modularity has increased. There are also substantial potential component markets for the focal firm. In the region labeled μ_3 (μ_4), firm 1 can sell component 1 (component 2) to customers. If there are enough customers whose preference vectors are within these market sets and if the component margins are large enough, unbundling may be profitable. Whether it is indeed preferable depends in detail on equation 11. It is possible that at time t_1 the growth in sales volumes is not sufficient to justify unbundling, but that at time t_3 it is.

Table B2
ATTRIBUTE VALUATIONS AND PRICES OF FOUR POSSIBLE SYSTEMS

	System 1	System 2	System 3	System 4
α_1 (component 1)	2.3	2.4	2.3	2.4
α_2 (component 2)	2.5	2.5	2.5	2.5
α_3 (integration)	2.0	1.9	1.9	1.95
α_4 (modularity)	1.6	1.7	1.7	1.7
P (price)	1.9	1.9	1.86	1.91

Figure B2
UNBUNDLED SYSTEM: LEFT FACE OF PREFERENCE PYRAMID



Market Volatility

Notice that when the firm retains a bundled system, though $\beta_{i,12}(t) \rightarrow 1$ for $i = 1, 2, 3$, $\beta_{4,12}(t)$ is bounded away from unity. If the prices of two systems are nearly equal, the intersections of their system planes with edges of the preference pyramid adjacent to the vertex associated with modularity are not close together. We can show (for $N = 2$) that the indifference surface moves only slightly if the price of a system is changed slightly. Small price changes create only small changes in sales volumes, provided the customer preference distribution is reasonably smooth. Hence an advantage of keeping a bundled system is that the market is likely to be relatively stable at any given time.

In contrast, if firm 1 unbundles system 1, all $\beta_{i,sw}(t) \rightarrow 1$. The trend over time is for all the systems' planes to be close together, if prices of the systems are nearly equal. The position of the indifference surface between the market sets for two systems can change substantially if the price of one of the systems is changed slightly. We demonstrate this price volatility with the following example.

Suppose P_3 is raised slightly, to 1.9, and all other attribute values and prices remain as indicated in Table B2. Part B of Figure B2 illustrates how the market sets change. System 3 is completely out of the market ($\mu_3 = \emptyset$). Hence, a disadvantage of unbundling is that the market is much more volatile.

REFERENCES

- Adams, William J. and Janet L. Yellen (1976), "Commodity Bundling and the Burden of Monopoly," *Quarterly Journal of Economics*, 90 (August), 475-98.
- Anderson, Paul F. and Terry M. Chambers (1985), "A Reward/Mechanism Model of Organizational Buying Behavior," *Journal of Marketing*, 48 (Spring), 7-23.
- Besen, Stanley M. and Leland L. Johnson (1986), *Compatibility, Standards, Competition, and Innovation in the Broadcasting Industry*. Santa Monica, CA: The RAND Corporation (November).
- Burstein, M. L. (1960), "The Economics of Tie-In Sales," *Review of Economics and Statistics*, 42 (February), 68-73.
- Dansby, Robert E. and Cecilia Conrad (1984), "Commodity Bundling," *American Economic Review*, 74 (May), 377-81.
- Farrell, Joseph and Garth Saloner (1985), "Standardization, Compatibility, and Innovation," *RAND Journal of Economics*, 16, 70-83.
- Guiltingan, Joseph P. (1987), "The Price Bundling of Services: A Normative Framework," *Journal of Marketing*, 51 (April), 74-85.
- Hanson, Ward and R. Kipp Martin (1990), "Optimal Bundle Pricing," *Management Science*, 36 (February), forthcoming.
- Hauser, John R. and Steven M. Shugan (1983), "Defensive Marketing Strategies," *Marketing Science*, 2 (Fall), 319-60.
- Heide, Jan B. and George John (1988), "The Role of Dependence Balancing in Safeguarding Transaction-Specific Assets in Conventional Channels," *Journal of Marketing*, 52 (January), 20-35.
- Jackson, Barbara B. (1985), *Winning and Keeping Industrial Customers*. Lexington, MA: Lexington Books.
- Katz, Michael and Carl Shapiro (1985), "Network Externalities, Competition, and Compatibility," *American Economic Review*, 75 (June), 424-40.
- Long, John B., Jr. (1984), "Comments on 'Gaussian Demand and Commodity Bundling'," *Journal of Business*, 57 (January), S235-46.
- Matutes, Carmen and Pierre Regibeau (1988), "'Mix and Match': Product Compatibility Without Network Externalities," *RAND Journal of Economics*, 19 (Summer), 221-34.
- Pfeffer, Jeffrey and Gerald R. Salancik (1978), *The External Control of Organizations: A Resource Dependence Perspective*. New York: Harper and Row Publishers, Inc.
- Phlips, Louis (1981), *The Economics of Price Discrimination*. Cambridge: Cambridge University Press.
- Porter, Michael E. (1985), *Competitive Advantage*. New York: The Free Press.
- Schmalensee, Richard (1984), "Gaussian Demand and Commodity Bundling," *Journal of Business*, 57 (January), S211-30.
- Stigler, George J. (1968), *The Organization of Industry*. Homewood, IL: Richard D. Irwin, Inc.
- Webster, Frederick E. and Yoram Wind (1972), *Organizational Buying Behavior*. Englewood Cliffs, NJ: Prentice-Hall, Inc.