PRODUCTION AND OPERATIONS MANAGEMENT
POMS
Vol. 14, No. 3, Fall 2005, pp. 315–330
ISSN 1059-1478 | 05 | 1403 | 315$1.25

Beyond Make-Buy: Internalization and Integration of Design and Production

Karl T. Ulrich • David J. Ellison
The Wharton School, University of Pennsylvania, 500 Huntsman Hall, Philadelphia, Pennsylvania 19104, USA
Monitor Company, 2 Canal Park, Cambridge, Massachusetts 02141, USA
ulrich@wharton.upenn.edu • david_ellison@monitor.com

Much recent attention in industrial practice has been centered on the question of which activities a manufacturing firm should complete for itself and for which it should rely on outside suppliers. This issue, generally labeled the "make-buy" decision, has received substantial theoretical and empirical attention. In this paper, we broaden the scope of the make-buy decision to include product design decisions, as well as production decisions. First, we examine independently the decisions of whether to internalize design and production, and then we consider how design and production organizational decisions are interdependent. The specific research questions we address are: (1) How can design and production sourcing decisions be described in richer terms than "make" and "buy"? (2) Do existing theories of vertical integration apply to product design activities as well as production decisions? (3) What is the relationship between the organization of design and the organization of production? (4) What organizational forms for design and production are seen in practice? After developing theoretical arguments and a conceptual framework, we explore these ideas empirically through an analysis of design and production sourcing decisions for bicycle frames in the U.S. mountain bicycle industry.

Key words: product design; make-buy decision; vertical integration; bicycle industry
Submissions and Acceptance: Received January 2004; revision received October 2004; June 2005; accepted January 2005.

1. Introduction

Much recent attention in industrial practice has been centered on the question of which activities a manufacturing firm should perform itself and for which it should rely on outside suppliers. A trend appears to be towards reducing the scope of internal activities and relying to a greater extent on suppliers. Yet, several very different organizational arrangements for design and production have been adopted in manufacturing firms. For example, in the computer industry, some firms perform both design and production internally. Other firms perform their own design, but contract with suppliers for production. In a third organizational form, a company such as Hewlett-Packard, contracts with a supplier to both *design and produce* products to its specifications. Similar alternatives seem to be present for the manufacture of automotive components, with some firms performing their own design and production; others performing design, but not production; and a third type relying on suppliers for both design and production. We are interested in explaining these organizational forms, and specifically, in understanding what, if any, connections there are between who performs design and who performs production.

The boundaries of the firm have been a central concern for several decades in the field of industrial organization, and there exists a wealth of theoretical and empirical analysis on the subject. Determining what to do in house versus what to outsource[1] is often called the *make-buy decision*, presumably because in manufacturing settings, the firm must decide which components of a product to make and which to buy from suppliers. The make-buy decision is equivalent

[1] We recognize that some people object to using the words "outsource" and "source" as verbs; however, this usage is dominant in industrial practice and so we adopt it here.

to a *vertical integration* decision when the firm faces a choice of whether or not to backward integrate a source of supply.

There are several gaps in the existing research. First, most empirical research is focused on a linear value chain involving the *production* of goods, ignoring design activities, which are essentially information processing activities. For example, Harrigan (1986) looks at production activities in industrial and consumer goods. Monteverde and Teece (1982a) and Walker and Weber (1987) study production of automobile components. MacDonald (1985) examines production decisions across SIC codes 20 to 39 (basic materials and assembled goods) and Masten (1984) looks at aerospace production. Notable exceptions to this generalization are Pisano (1990), who examines R&D sourcing decisions in the biotechnology industry, and Novak and Eppinger (2001) who study automotive component sourcing. Second, the literature tends to address the decision to integrate a single activity in isolation, and tends not to consider interactions between two or more sourcing decisions. In our case, we are interested in both *design* and *production*, and believe that design and production decisions are often interdependent and cannot always be analyzed in isolation. Third, much of the research on make-buy does not distinguish between the sourcing of standard components and the sourcing of product-specific components. As a result of these factors, for example, the "buy" category is used to describe some very different situations, including:

- sourcing production of a product-specific component that is designed internally,
- "black-box" sourcing of a product-specific automotive component in which both design and production are done by a single supplier (Asanuma 1985; 1989; Clark 1989; Clark and Fujimoto 1991; Liker et al. 1996),
- sourcing of a product-specific component in which one supplier does the design and a second does production, and
- sourcing of a standard component from the catalog of a supplier.

In this paper, we broaden the scope of the make-buy decision to include *product design* decisions as well as production decisions. The specific questions we address are: (1) How can design and production sourcing decisions be described in richer terms than "make" and "buy"? (2) Do existing theories of vertical integration apply to product design activities as well as to production? (3) What is the relationship between the organization of design and the organization of production? (4) What organizational forms for design and production are seen in practice?

While our principal focus is product design and production, our theory applies to the general problem of industrial organization of a network of interconnected activities, some of which may be information processing activities, while others may involve the transformation of physical materials.

We apply and interpret existing theory of industrial organization in the context of product design and production. We add to this theory by articulating a distinction between internalization and integration, and by considering the coupling among sourcing decisions. We then explore our theory with an empirical analysis of bicycle frame sourcing in the U.S. mountain bicycle industry.

1.1. Conceptual Framework

We focus on engineered goods and we assume the perspective of a firm supplying a branded product to the market. We assume that this firm also *specifies* its products (i.e., deliberately designates the characteristics of the products it intends to supply). We call such firms *manufacturers*, although they may or may not literally produce their own products. A central challenge of the manufacturer is to arrange for the completion of a set of design and production activities in order to deliver its products to the market.

In the literature on industrial organization, there are two classic approaches to the organizational challenge of coordinating these design and production tasks: *markets* and *hierarchies* (Williamson 1975). Markets rely on self-interested exchanges (selling and buying) on the part of suppliers and purchasers to coordinate the completion of work. Hierarchies rely on the authority associated with legal ownership to assign and monitor work to subsidiary entities. This classification is complicated in practice by the widespread use of intermediate forms. Contractual arrangements, while generally considered market mechanisms, can detail the terms and conditions of a transaction and anticipate some contingencies. Furthermore, some wholly owned subsidiaries of manufacturers behave in many respects as if they were independent suppliers operating in a competitive market.

1.2. Distinction between *Internalization* and *Integration*

The literature generally considers the organizational integration of activities along a linear, temporal sequence of physical transformation processes. *Vertical integration* within this framework is the consolidation of successive stages of this sequence into the same legal entity.

In our work, we make a distinction between *internalization* and *integration*.

- **Internalization** is the inclusion of an activity within the organizational boundaries of the manufacturer, the entity on which our analysis focuses.
- **Integration** is the consolidation of two or more

activities into the same organizational entity, *whether or not this entity is the manufacturer*. Note that when this consolidation of activities occurs within the manufacturer, the activities are both integrated and internalized. That is, if two activities are internalized, they are also integrated. However, the converse is not always true: two activities can be integrated into the organization of a single supplier and not be internalized with respect to the manufacturer. Note that we use *integration* to refer to the inclusion of two activities within the scope of the same organization and not to the technological activity of integration in the sense articulated by Iansiti (1998).

In the next section, we review the basic motives for internalizing or not internalizing (i.e., outsourcing) an activity. We discuss the implications of these motives for both production and design activities. Section 3 combines these perspectives into implications for organizational structure. Section 4 tests the key ideas of the paper with empirical evidence from the mountain bicycle industry. Section 5 contains discussion and concluding remarks.

2. Internalization and Integration in Activity Networks

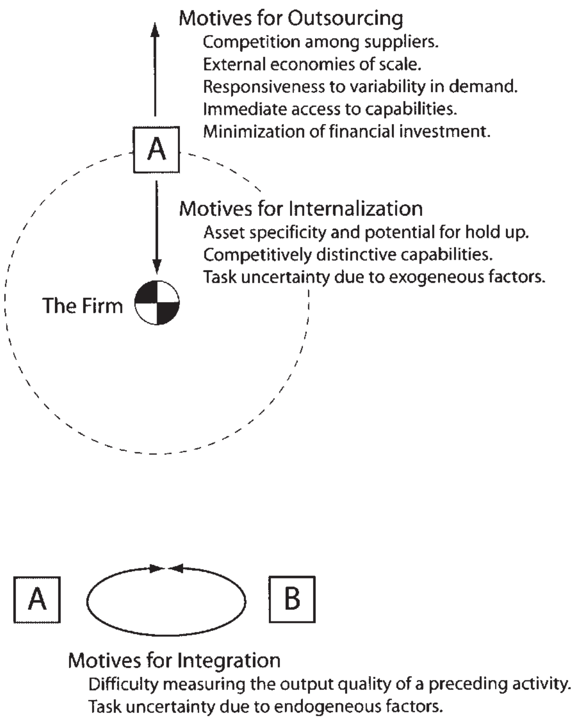
In this section, we first consider the motives for *not* internalizing an activity (i.e., for outsourcing) and then consider when internalization may offer benefits to the firm. We then outline the motives for integrating two activities, whether or not they are internalized. These motives are summarized in Figure 1. Note that many of the issues discussed in this section and the next have been well established in prior theoretical and empirical work. We provide this review to consolidate the arguments, and for the benefit of those readers who are not familiar with the relevant literature. Those familiar with this literature may skip to Section 3. For those interested in reviewing this literature in more detail, see Mahoney's comprehensive review (1992) or the textbook by Tirole (2001).

2.1. Outsourcing Versus Internalization

The market mechanism of organizing manufacturing (i.e., outsourcing) offers several compelling potential benefits to a manufacturer.

Competition Among Suppliers. Heralded for more than 200 years, the benefit of competition among suppliers in a free market is the most fundamental of motives and generally forms the backdrop against which all other factors are considered (Smith 1776). All other factors equal, competition among suppliers should offer potential benefits for outsourcing both physical production activities and the information processing activities associated with product design.

Figure 1 (A) Summary of motives for outsourcing versus internalizing an activity A, and (B) summary of motives for integrating activities A and B, whether or not they are internalized.



Conversely, a lack of competition among many suppliers (i.e., supplier concentration) creates an incentive for the manufacturer to internalize an activity in order to avoid the exercise of monopoly power by a supplier. This dynamic of internalization in response to supplier concentration has been articulated by Fine (1999; 2000) for the computer and automobile industries.

External Economies of Scale. When a supplier provides goods or services to many customers, this supplier may achieve greater economies of scale than could a customer providing the same goods or services for itself. Achieving this benefit requires that the goods or services be standardized and that there be fewer suppliers than customers. (See Thompson 1954 for a fascinating discussion of this phenomenon in the early automobile industry.) External economies of scale are familiar in component production, yet may also be present in product design. For example, when designers can employ expensive and specialized automation tools, may be scale advantages to procuring these design services from a supplier who specializes in these activities.[2]

Responsiveness to Variability in Demand. A basic

[2] Although work by Zenger (1994) suggests that there may be diseconomies of scale in research and development due to smaller firms' abilities to offer employment contracts that are more closely tied to individual performance.

result from statistics and queueing theory is that when independent sources of demand are pooled, then the variability in aggregate demand is less than that of these independent sources. This property implies that for a given required lead-time, the capacity required for a shared resource can be substantially less than the sum of the capacities required to service multiple sources of demand independently[3]. These economies apply to both design and production activities. Design activities tend to experience substantial variability in demand, because the timing of episodes of product development is often more "lumpy" than are the production schedules of the associated products.

Immediate Access to Capabilities. A firm pursuing a new market opportunity or employing a new product or process technology may need access to a new capability immediately. Many such capabilities require time to procure internally and so, in the short term, a manufacturer must outsource an activity to a competent supplier. This is a transient issue, in that most capabilities can be acquired through investment of time and/or money. This factor applies to both design and production activities.

Minimization of Financial Investment. Acquiring a capability generally requires a financial investment of human or physical capital. One way to avoid the investment is to outsource design and/or production to a firm that already possesses the required capabilities. Uncertainty about the future use of a capability decreases the attractiveness of an investment in internalization. Such uncertainty is common in component technologies and firms may outsource component design and production to a supplier to avoid having to "make a bet" on a single component technology (Balakrishnan and Wernerfelt 1986; Lewis and Sappington 1991[4]).

2.2. Motives for Internalization

Since Coase's seminal work (1937), researchers have developed theories to explain the existence of firms, i.e. why vertical integration is advantageous. Much of this work falls into the category of transaction cost economics (TCE). This theory is complemented by agency theory and by theories of firm *capabilities* developed in the field of competitive strategy. Together, these theories present several clear motives for internalization.

Asset Specificity and Potential for "Hold Up." Transaction cost economics (TCE) is built on the premise that firms organize to minimize transaction costs, which include the costs of arranging for and monitoring the procurement of goods and services. Within the TCE paradigm, these costs can be very high in the presence of *specific assets*, those assets that a supplier requires to provide a good or service and that are unique to the needs of a single customer. Williamson (1985) classifies specific assets as *human*, *physical*, and/or *site*. In the presence of such assets, both supplier and customer face *small-numbers bargaining* (Williamson 1975) and the associated threat of opportunistic behavior on the part of the other party. TCE predicts that in the presence of specific assets, firms will tend to vertically integrate the activities employing these assets to avoid this risk. These arguments potentially apply to both design and production activities. Most of the literature addresses production activities where specific assets include equipment, geographic proximity, or specialized knowledge. However, design may also involve substantial human asset specificity in the form of the knowledge and capabilities of product designers. Pisano (1990) empirically validates the role of asset specificity in the internalization of R&D activities in biotechnology firms.

Competitively Distinctive Capabilities. A central idea in the field of competitive strategy is that a firm is a locus of competitively distinctive capabilities. Because these capabilities can be quite "sticky" (i.e., difficult to transfer), a firm can develop a competitive advantage by investing in their development. See Teece, Pisano, and Shuen 1997 for an excellent survey of the literature on this subject. The development and preservation of capabilities can be a motive for internalizing design and/or production activities. In situations where the design of a product is competitively distinctive, design capabilities are likely to be important; and the preservation and development of those distinctive capabilities is likely to be enhanced by internalizing the design activity (Iansiti and Clark 1994). There are also appropriability issues associated with design and production activities. When outsourcing an activity, there is a risk that intellectual property may spill over to competitive firms (Teece 1986). Similarly, outsourcing an activity to a supplier presents a risk that this supplier may develop into a competitor. These risks may motivate a firm to internalize activities critical to its competitive advantage. Finally, maintaining internal design and production capabilities may enhance the ability of a firm to understand and assimilate innovations external to the firm (Cohen and Levinthal 1990; Parker and Anderson 2002).

Task Uncertainty Due to Exogenous Factors. Outsourcing generally requires that a contract can be written that anticipates likely contingencies. Creating a robust contract will be difficult in situations where there is a high likelihood of an unpredictable exogenous disturbance in the task requirements, perhaps

[3] See Hopp and Spearman 1996, Chapter 8 for a basic discussion of the role of pooling in capacity utilization.

[4] Lewis and Sappington engage similar issues to Balakrishnan and Wernerfelt, but with differing conclusions.

due to an unexpected change in market requirements. When unanticipated disturbances occur, contract renegotiation is likely, with the associated small-numbers bargaining problems. As a result, the firm is likely to wish to internalize the activities subject to such disturbances (Crocker and Masten 1988; Masten et al. 1991). This is a factor often included within TCE and it applies to both design and production activities.

The difficulties presented when outsourcing in the presence of asset specificity or task uncertainty may be overcome in theory by vertical integration. This is because for activities and actors within a single legal entity, there is direct authority to compel action without litigation. Internalization may also overcome these difficulties through the development of a sense of community, a beneficial culture or clan-like behavior (Kogut and Zander 1996; Ouchi 1980). Legal ownership may not be strictly necessary to achieve many of the benefits of internalization. Dyer (1997) provides compelling evidence of non-ownership modes of integration, such as relational trust, that can allow two firms to engage in market exchange with diminished risks of opportunistic behavior.

2.3. Motives for Integrating Activities

From the perspective of the manufacturer, integration is distinct from internalization when the activities to be integrated are both candidates for outsourcing, and the activities could be integrated within a single supplier. There are two basic motives for integrating two activities into the same organizational entity, even when these activities are external to the manufacturer.

Difficulty Measuring the Quality of Output of a Precedent Activity. There is a strong motive to integrate two interrelated activities A and B into the same organizational entity when the output of Activity A is required for completion of the Activity B, and when the quality of the output of Activity A is difficult to assess. Such situations present classic agency problems in that the organization responsible for the first activity could shirk without detection (Alchian and Demsetz 1972; Holmstrom and Milgrom 1991). By integrating the two activities into the same organizational entity, responsibility for the pair of activities resides with the same agent.

Task Uncertainty Due to Endogenous Factors. Some pairs of design and production activities are highly interdependent. In product design, situations arise in which completion of one activity requires information from the other activity, and the structure of the information exchange cannot be anticipated in advance. Such pairs of activities are said to be *coupled* and generally require an iterative exchange of information and cooperative resolution of decision parameters in order to achieve a good joint solution (Thompson 1967; Krishnan, Eppinger, and Whitney 1997; Loch and Terwiesch 1998). In these situations, it is difficult to contract for the completion of a single activity, and much simpler to contract for the completion of the pair of activities.

Explicit codification of design rules allows component production and component design activities to be disintegrated. Design rules are an instance of the use of standards as a coordination mechanism (Galbraith 1974; Baldwin and Clark 1999). The interdependency of component design and component production is the focus of substantial work on *design for manufacturing* or *DFM* (Ulrich and Eppinger 2004). When the component production process is stable and well understood, then it is often possible to establish design rules that express the constraints of the production process (Adler 1995). Designers can then specify the geometry and material properties of the component in a way that it can be made without complication on the intended production process. Such design rules exist formally for integrated circuits and printed circuit boards, and exist less formally for many metal forming and plastics processing processes. However, when the process is new, unusual, and/or poorly understood, there are generally no design rules. Feasible designs are established through trial and error or through dialogue between production process experts and component designers. For example, the production processes for many composite materials (e.g., graphite-fiber-reinforced polymers) are poorly understood and/or highly complex. As a result, component design of composite materials must often be conducted iteratively with the trial and refinement of the production process, or at a minimum with strong communication between process experts and component designers (Fine and Whitney 1996). Monteverde (1995) calls this kind of interaction between designers and production personnel "unstructured technical dialog," and finds empirical evidence in the semiconductor industry that its presence is a significant motive for integration of design and production.

3. Implications for Organizational Structure

In Section 2, we argued that there is a set of motives for internalizing or outsourcing design and production activities, and that there is a set of motives for integrating pairs of design and production activities. These motives, when taken together, comprise a collection of influences on the organization of design and production, and a rational organizational structure reflects a resolution of the entire set of influences. Here, we attempt to consolidate the various factors into a framework for making and/or explaining organizational design decisions.

The organizational problem we address is how to assign the activities in a value network to one or more organizational entities. For simplicity, consider two activities, A and B, which might be thought of as component design and component production, and assume the perspective of a manufacturer with a single potential supplier. There are four distinct organizational schemes in this situation, illustrated in Figure 2.

In case 1, assume that there are motives to internalize activity A, internalize activity B, and to integrate activities A and B. In this case, a straightforward response to these motives is the internalization of both A and B. This organizational scheme both internalizes and integrates the two activities.

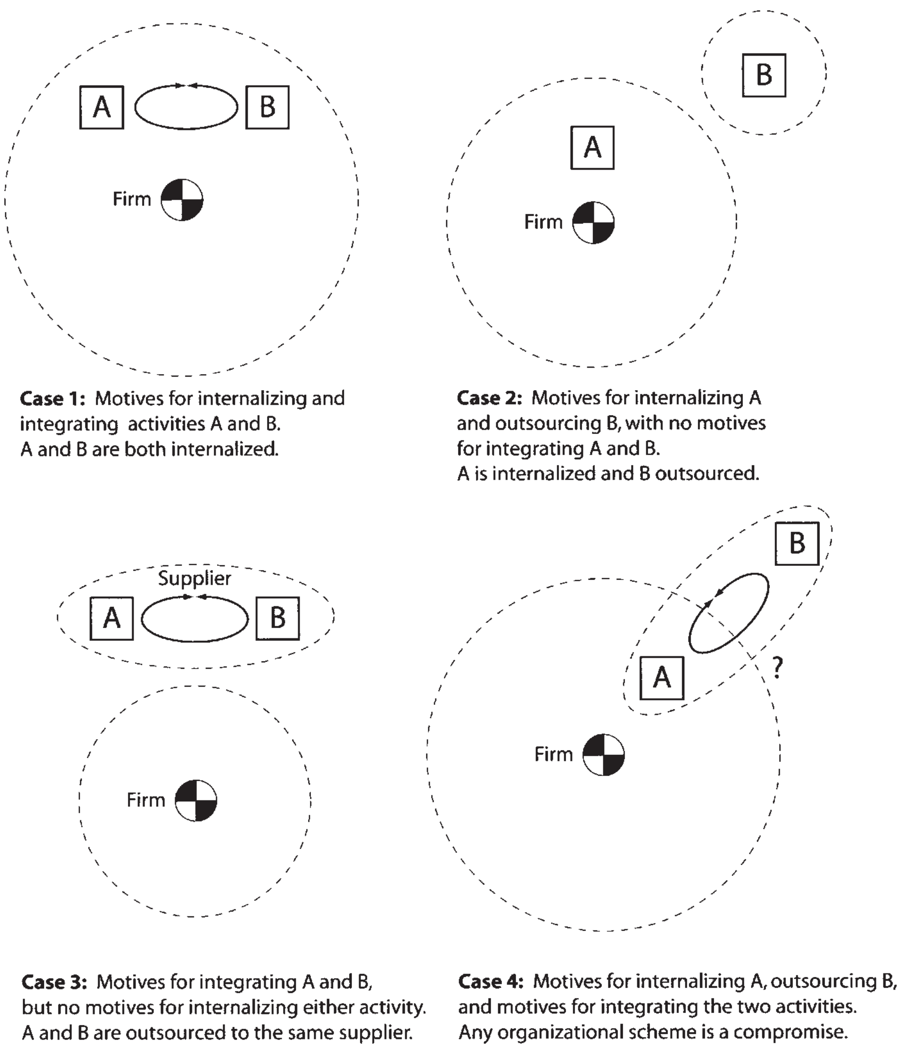
In case 2, assume that there are motives to internalize A and motives to outsource B. There are no motives to integrate A and B. In this case, a harmonious organizational scheme is one in which A is internalized and B is outsourced to a supplier.

In case 3, assume that there are motives for integrating activities A and B and no motives to internalize either activity. In this case, an organizational scheme consistent with these motives assigns both A and B to a single supplier.

In case 4, assume that there are motives to internalize activity A, to outsource activity B, and to integrate A and B. In this case, there is no organizational scheme that will cleanly respond to these conflicting motives. Either A and B are assigned to a single supplier, A and B are internalized, or A is internalized and B outsourced. Any of these three organizational schemes is a compromise.

This framework highlights situations in which organizational structures are likely to function harmoniously and situations in which conflicting motives are likely to present managerial challenges. Given the reality of conflicting organizational motives, there are mechanisms for addressing the potential weaknesses in an organizational solution. After describing our

Figure 2 **Four possible cases reflecting different motives for internalization and integration and different organizational schemes.**



empirical exploration, we revisit this issue using examples from the mountain bicycle industry to illustrate ways to handle these potential weaknesses.

4. Empirical Exploration

We empirically explore the concepts developed in the previous sections by studying design and production sourcing decisions in the U.S. mountain bicycle industry. Our goal is to examine the extent to which the theoretical framework of internalization and integration explains the organization of design and production in different firms in the industry.

The United States bicycle market constitutes approximately 10 percent of the 100 to 130 million unit world bicycle market. Approximately 75 percent of all bicycles in the U.S. are sold through the mass-merchandising channel. Bicycles sold through this channel are typically children's bicycles and adult bicycles priced below $200. The remaining 25 percent of U.S. bicycle sales occur through independent bicycle dealers (IBDs). Ninety-five percent of all bicycles priced above $200 are sold through IBDs. We focus on this "over $200" portion of the market because this price category and channel of distribution define a relatively independent set of competitors exhibiting a great deal of organizational diversity. As of 1997, there were approximately 6,000 IBDs in the U.S. with 1,500 dealers accounting for 60 percent of all unit sales. Total unit sales have been fairly constant over the past decade, but the proportion of "mountain bikes" has increased from 12 percent in 1985 to over 50 percent today.

We focus on the industry in 1997, a time in the industry lifecycle in which mountain bike frame technology was in flux and in which there was substantial variance in organizational choices. Over 75 firms competed in the over-$200 category, allowing for substantial natural variation in strategies. (See Ulrich et al. 1999 for a more general discussion of competitive strategies in the bicycle industry.)

A mountain bicycle is generally thought of as consisting of a frame plus components (Figure 3). The frame is generally a tubular structure and the components (e.g., brakes, seat, crank set, wheels, derailleurs) are mounted to the frame. Our empirical analysis focuses on the frame, because we believe that the frame is the component around which there is the most variation in industrial practice, and around which the organizational problems are most challenging. Nearly every mountain bike manufacturer purchases several major power train components and/or braking components from a few large suppliers. Other components, such as tires, rims, spokes, seats, and handlebars are obtained from a variety of smaller suppliers. Most of the components attached to a bicycle frame

Figure 3 **A basic mountain bicycle with no rear suspension (a "hard tail") and conventional frame material. (Courtesy of Cannondale.)**

are *selected*. That is, they are standard components available from the catalog of a supplier. The only component that is consistently uniquely designed for each new version of a product is the frame. The frame is also the component that is most closely identified with the bicycle brand and is generally the first element of the product considered when a customer makes a buying decision.

4.1. Application of Theory

We consider the design and production activities for the bicycle frame. In 1997, there was a very healthy frame supply base in the U.S. and Asia, and manufacturers had the luxury of several alternatives for designing and producing frames. In theory, there are four basic options available to the manufacturer. The manufacturer can choose to do frame design internally or externally and can choose to do frame production internally or externally. When frame design and frame production are done either both internally or by the same supplier externally, then these activities are integrated.

Internalizing/Outsourcing Frame Design. The motives for internalizing design can be quite prominent in the case of bicycle frames. For some firms, design distinctiveness is the primary basis of their competitive strategies, and so these firms are likely to internalize frame design. This is consistent with both the TCE view of integration and with the capabilities view of integration. From a TCE perspective, knowledge and skill related to a proprietary product design are highly specific assets. Allowing a supplier to harbor these assets presents high risks of hold-up and opportunistic behavior. From a capabilities perspective, if the basis of competition is the distinctiveness of the bicycle frame, then the firm will wish to cultivate this capability for itself. In mountain bike design, the most active area of proprietary frame design is the suspension. Nearly all manufacturers offer "hard tails," bicycles with no rear suspension. Some of these manufacturers offer bikes with rear suspension, and rear suspension configuration is a primary differentiating attribute of many bicycle brands. See Figure 4 for an example of a unique full suspension design. We would therefore expect that firms that offer full suspension frames and that compete based on the uniqueness of their suspension designs would benefit from internalizing the frame design activity. Other firms, who presumably compete on some other basis (e.g., distribution, value, service, etc.) would not benefit substantially from such internalization.

In Section 2, we identified several motives for outsourcing an activity: benefits of competition among suppliers, external scale economies, smoothing of demand volatility, access to capabilities, and minimizing financial investment. These factors do not appear to be dominant in the design sourcing decision for bicycle frames. The benefits of competition are always present whenever there are many suppliers and this benefit is essentially the backdrop against which the other factors are considered. The capital investment for the frame design activity is relatively small (e.g., \$10,000 for a workstation and software for an engineer). There is relatively little design automation. Therefore, scale economies are not prominent in frame design and minimizing financial investment is therefore also not a large factor. Because there is strong seasonality in the bicycle industry (K2 Inc. 2003), the variability in demand for frame design is highly correlated across firms. This means that there are no benefits to outsourcing frame design in terms of smoothing variability in demand. Access to capabilities could be a factor in deciding to outsource frame design for a new firm. However, the firms in our study have all been operating at least five years, which is ample time to develop a frame design capability, if desired. Integrating these factors, we can formulate the following hypothesis.

Hypothesis 1. *Firms that offer unique suspension designs internalize the design activity, ceteris paribus.*

Figure 4 Example of a full suspension mountain bicycle with a unique suspension design. (Courtesy of Cannondale.)

Internalizing/Outsourcing Frame Production. The dominant factor associated with internalfizing/outsourcing frame production is economies of scale. Economies of scale are, of course, driven by unit volume, but also by the number of different basic materials used in frame processing. The number of materials in use is important because each different material requires a substantially different production process. Aluminum requires heat treating. Titanium requires special tube cutting tools. Graphite-fiber-reinforced polymer (GFRP) requires molds, special adhesives, and curing ovens. As a result, for the same unit volume, firms that offer only one material achieve more significant economies of scale than do firms offering several materials. Therefore, we would expect firms that do not have the minimum efficient scale in any one material to benefit from outsourcing production of at least the frames made from that material.

The competitive strategies of a few manufacturers revolve around expertise processing a particular material. This is true, for example, of Merlin[5] (titanium) and Kestrel (GFRP). These firms offer one and only one material and were pioneers in developing the production processes for these materials in the context of bicycle frames. For such firms, we would expect frame production to be internalized. Note that the competitive strategies of these firms are sustainable only as long as processing of these materials is not widely available from independent suppliers offering production capabilities to any manufacturer.

The remaining generic factors associated with internalization or outsourcing are present to some extent, but do not appear to be prominent in frame production. Because of seasonality, most firms choose to hold finished goods inventory, and so there are few potential benefits from the smoothing of the stochastic component of demand that could result from outsourcing production. Some firms may have a transient need to acquire a particular production capability (e.g., titanium fabrication), but the materials options were stable from 1993 to 1997, so that firms desiring internal frame production capability could have acquired it. There are few specific assets in frame production. There are four basic material processing alternatives and these processes are widely applicable in the industry. There is some product-specific tooling, but a common practice is for manufacturers to own the specific tooling used by suppliers in order to mitigate asset specificity problems (Monteverde and Teece 1982b). Two additional hypotheses arise from these factors.

Hypothesis 2. *Firms that compete on the basis of unique materials processing capabilities internalize production, ceteris paribus.*

[5] These firms are not in our data set, and so we use their real names.

Hypothesis 3. *Firms that lack scale and that do not compete on the basis of unique materials processing capabilities outsource production, ceteris paribus.*

Integration of Design and Production. We argued in Section 2 that the primary motive for integrating component design and component production is a lack of design rules for the production process. The emergence of design rules generally occurs as production processes mature. In frame production, the maturity of the production process is closely related to the length of time a frame material has been in widespread use. Currently, there are three relatively new materials in bicycle frames: titanium, graphite-fiber-reinforced polymers (GFRP), and metal-matrix composites. A bicycle with a frame made from GFRP is shown in Figure 5. Of course "newness" is a transient property of a material. In 1980, aluminum would have been considered a new material, but in 1997, it was extremely common and the aluminum frame production process was well understood. When a material and its associated fabrication process are new, designers must collaborate closely with those operating the production process to arrive at a design that both functions as desired and can be feasibly and economically produced. Therefore, we would predict that frames employing new materials would benefit from being both designed and produced by the same organizational entity. This factor gives rise to a final hypothesis.

Hypothesis 4. *Firms that employ new frame materials either internalize both frame design and frame production or outsource these activities to the same supplier, ceteris paribus.*

4.2. Sample and Data Collection

Using *Bicycling Magazine*'s annual buyer's guide, and market share information from a *Bicycling* readers' survey, we identified the 25 largest mountain bicycle companies operating in the United States. Representatives from these companies were contacted by telephone and asked to fill out a written questionnaire. Of these, 17 actually completed the survey. Two companies refused to participate and the others did not respond after agreeing to participate. Coincidentally, there happens to be a great deal of public information available for the two companies who refused to participate, and so we were able to determine the values of the study variables for these companies through independent sources. Therefore, the sample comprises 19 of the top 25 companies in the industry, representing approximately 90 percent of the unit sales of over $200 mountain bicycles in the United States. The questionnaire was six pages long and contained 53 detailed questions about the company's design, marketing, and operations practices. The survey was pre-tested with five companies and revised based on the comments of the respondents. A copy of the survey is available from the authors upon request.

Figure 5 An example of a mountain bicycle with a frame made from a "new material"—graphite fiber reinforced polymer. (Courtesy of Trek.)

We focused on the design and production sourcing decisions for frames associated with the highest-priced models in each of the firm's product categories (e.g., aluminum "hard tail", titanium full suspension, aluminum downhill, etc.). We focused on the high-end models because these models exhibit the most variance in sourcing decisions and because it was infeasible to consider every frame sold by every manufacturer.

In most cases, our unit of analysis is the firm. In theory, it would make sense to use the individual frame as the unit of analysis, and we did collect frame-level data. However, with three exceptions in our sample, firms make consistent decisions across all the high-end bikes in their product lines. Therefore, we feel it is more appropriate to consider the firm as the unit of analysis. For the three exceptions, we create a separate observation for each different type of sourcing decision made by the firm.

The study variables are as follows:

***D*, Design** (0,1). D is 1 if the frame design activity is performed internally and 0 if it is performed by a supplier. We defined frame design as the activity in which computer models or drawings are created.

***P*, Production** (0,1). P is 1 if the frame production activity is performed internally and 0 if it is performed by a supplier. No manufacturer makes tubing or other raw materials, and so frame manufacturing always and unambiguously comprises frame fabrication and finishing.

***M*, New Material** (0,1). M is 1 if the firm offers frames made from titanium, GFRP, or metal-matrix composite; and 0 otherwise (i.e., for firms offering frames made only from steel or aluminum).

***S*, Unique Suspension** (0,1). Firms offering full suspension designs were asked to assess the uniqueness of their own full suspension designs on a scale from 1 (not unique) to 7 (highly unique). Unique-Suspension is 1 for firms with a self-reported suspension rating of 4 or greater; and 0 otherwise. This variable is 0 for firms that do not offer frames with full suspension. We believe that self-assessment of suspension uniqueness is appropriate because the relevant factor is how the firm has conceived of its competitive strategy, not necessarily how well it has executed that strategy.

***Q*, Quantity** (0,1). Q is 0 if the firm lacks efficient scale and 1 if the firm has achieved minimum efficient scale. We estimate the relative scale of a company by first estimating annual unit volume (Table 5). Respondents were provided with seven volume categories to choose from. Our estimate of volume is usually the mid-point of the range used to define a category. However, the highest-volume choice was unbounded (>200,000 units/year). We use a volume estimate of 300,000 for firms in this category[6]. We then estimate the average volume of each basic material used by the firm, i.e., volume/N, where N is the number of basic materials used by the firm (e.g., aluminum, steel, titanium, GFRP). When volume/N is greater than 50,000 units per year, then Q is 1, and is 0 otherwise. Volume is typically not distributed evenly across the materials, but the average volume per material gives an approximation of the scale of the company. The choice of a volume cut-off of was based on discussions with industry experts, but there are only two firms with values near the cut-off of 50,000 units per year. Our results would not change significantly if this cut-off were anywhere between 38,000 units per year and 100,000 units per year.

***U*, Unique-Process** (0,1). U is 1 if the firm employs a competitively distinctive process in production, and 0 otherwise. Based on interviews with five industry experts, we identified three firms in the sample for which such capabilities are a key basis of competition. Crestone[7] and Cannon compete in part by offering unique composite frame technology. In both cases, the technology is given a trademark and is prominent in the firms' positioning of the products made with the technology. Shasta specializes in titanium frames, entered the bicycle market from the specialty titanium fabrication business, and is known in the market as the leading titanium processor. These are unambiguously the only firms in this category and there was no disagreement about this categorization. For these three firms, we assign U a value of 1.

In sum, we hypothesize that for internally consistent organizational decisions:

H1. *a firm with competitively unique suspensions performs frame design internally*;

H2. *a firm with competitively unique production processes performs frame production internally*;

H3. *a firm that does not produce quantity sufficient to achieve minimum efficient scale, and that does not have unique production processes, outsources production*;

H4. *a firm using new frame materials either does both frame design and production internally or outsources both activities to the same supplier*.

Note that we are not assuming causality in making these arguments. For example, we are not necessarily asserting that firms wishing to offer unique suspension designs therefore choose to internalize their frame design activity. Rather we are asserting that unique suspension design and internalized frame design form a coherent pair of marketing and organizational decisions. An alternative interpretation is that a firm with existing internal design capability chooses to pursue a market strategy based around unique suspension design, or that this design capability and market strategy evolved simultaneously. These interpretations are also consistent with our theory.

4.3. Empirical Evidence

There are 16 possible combinations of the 2 values (0,1) for the 4 variables (Q, U, S, and M). There are four possible organizational forms corresponding to outsourcing or internalizing design or production (D = 1/P = 1, D = 1/P = 0, D = 0/P = 1, and D = 0/P = 0). This combination of 4 organizational choices for 16 combinations of the contextual variables leads to 64 possible scenarios. In Table 1, we display these 64 scenarios and we indicate with shading the scenarios that exhibit *misfit* with respect to one or more hypotheses. The specific hypotheses responsible for the misfit are noted in the cells.

The values of the study variables and the actual organizational choices for our 23 observations are shown in Table 3. Although we intend the theory to be evaluated as an integrated whole, as a first-order test, we can evaluate the predictions of the hypotheses taken individually. These results are shown in Table 4. This first-order analysis provides statistically significant support for Hypotheses 1, 2, and 3. The results for Hypothesis 4 are in the predicted direction, but not statistically significant given only 10 relevant observations. In Table 2, we populate the 64 possible scenarios with the 23 empirical observations. We can assert with statistical confidence that the empirical observations are not randomly distributed among the 64 cells. However, a statistically valid analysis of the integrated theory, including a simultaneous test of all four

[6] Our results are not sensitive to this estimate, and we would make identical predictions if we used a value of 200,000.
[7] All names of firms in this section are disguised.

Table 1 All 64 Possible Organizational Scenarios. Four Possible Organizational Choices are Shown for Each of the 16 Combination of *Q*, *U*, *S*, and *M*. The Shaded Cells Represent "Misfit" According to our Theory. The Hypotheses with which the Configuration does not Fit are Noted in the Cells

	Q Quantity	*U* Unique process	*S* Suspension unique	*M* Material new	$D = 1/P = 1$ *D* internal + *P* internal	$D = 1/P = 0$ *D* internal + *P* external	$D = 0/P = 1$ *D* external + *P* internal	$D = 0/P = 0$ *D* external + *P* external
a	1	1	1	1	√	H2, H4	H1, H4	H1, H2
b	1	1	1	0	√	H2	H1	H1, H2
c	1	1	0	1	√	H2, H4	H4	H2
d	1	1	0	0	√	H2	√	H2
e	1	0	1	1	√	H4	H1, H4	H1
f	1	0	1	0	√	√	H1	H1
g	1	0	0	1	√	H4	H4	√
h	1	0	0	0	√	√	√	√
i	0	1	1	1	√	H2, H4	H1, H4	H1, H2
j	0	1	1	0	√	H2	H1	H1, H2
k	0	1	0	1	√	H2, H4	H4	H2
l	0	1	0	0	√	H2	√	H2
m	0	0	1	1	H3	H4	H1, H3, H4	H1
n	0	0	1	0	H3	√	H1, H3	H1
o	0	0	0	1	H3	H4	H3, H4	√
p	0	0	0	0	H3	√	H3	√

Note. The configurations in row m allow no organization of design and production that avoid misfit under our theory. Of the four organizational alternatives, however, one exhibits greater misfit than the others (indicated with shading).

hypotheses that would illuminate the role of each variable is not feasible with 64 possible logical cells and only 23 observations.

5. Discussion

5.1. Discussion of Outliers

Examination of the decisions that are not consistent with our theory is instructive. There are three such cases. In the case of Everest 2, we predicted that the firm would internalize design because it offered a unique suspension design; but instead it outsources design. Interestingly, this firm licenses two suspension patents from a leading independent suspension designer with a background in motorcycle design. The existence of patents mitigates some of the appropriability concerns associated with outsourcing design, and allows this company to both have a unique design and to outsource the design to its supplier. Note that our definition of design is also important here. We measured who does design by who controls the computer-aided design model of the product. In this case, the firm specifies the basic geometry of the frame, derived from the patent, and then the supplier completes the details of the design.

The same manufacturer internalizes design and outsources production of a frame built from a new mate-

Table 2 All 64 Possible Organizational Scenarios with Empirical Observations Noted as ■

	Q Quantity	*U* Unique process	*S* Suspension unique	*M* Material new	$D = 1/P = 1$ *D* internal + *P* internal	$D = 1/P = 0$ *D* internal + *P* external	$D = 0/P = 1$ *D* external + *P* internal	$D = 0/P = 0$ *D* external + *P* external
a	1	1	1	1	■■			
b	1	1	1	0				
c	1	1	0	1				
d	1	1	0	0				
e	1	0	1	1	■■			■
f	1	0	1	0	■■	■		■
g	1	0	0	1		■		
h	1	0	0	0				■■
i	0	1	1	1	■			
j	0	1	1	0				
k	0	1	0	1				
l	0	1	0	0				
m	0	0	1	1		■		■
n	0	0	1	0		■■■		
o	0	0	0	1				■
p	0	0	0	0		■		■■■■

Table 3 **Actual Organizational Choices for Firms and Frames in the Sample. The Three Firms in Bold Exhibit "Misfit" in their Organizational Choices According to our Theory**

Firm/Frame	Case	*Q* Quantity	*U* Unique process	*S* Suspension unique	*M* Material new	*D* Design internal	*P* Production internal	*D* and *P* integrated?
Cannon	a	1	1	1	1	1	1	1
Crestone	a	1	1	1	1	1	1	1
Everest 1	e	1	0	1	1	1	1	1
Baker	e	1	0	1	1	1	1	1
Kilimanjaro	**e**	**1**	**0**	**1**	**1**	**0**	**0**	**1**
Denali	f	1	0	1	0	1	0	0
Matterhorn	f	1	0	1	0	1	1	1
Mitchell	f	1	0	1	0	1	1	1
Everest 2	**f**	**1**	**0**	**1**	**0**	**0**	**0**	**1**
Everest 3	**g**	**1**	**0**	**0**	**1**	**1**	**0**	**0**
Teton	h	1	0	0	0	0	0	1
Vesuvius	h	1	0	0	0	0	0	1
Shasta	i	0	1	1	1	1	1	1
Ras Dashon	m	0	0	1	1	1	0	0
Snowmass	m	0	0	1	1	0	0	1
Mont Blanc	n	0	0	1	0	1	0	0
Olympus 1	n	0	0	1	0	1	0	0
Ranier	n	0	0	1	0	1	0	0
Olympus 2	o	0	0	0	1	0	0	1
Washington	p	0	0	0	0	0	0	1
Whiteface 2	p	0	0	0	0	0	0	1
Whitney	p	0	0	0	0	0	0	1
Whiteface 1	p	0	0	0	0	1	0	0

rial (Everest 3). However, it outsources to a supplier that is located only a short drive away from the office in which the designers work. This allows the two firms to coordinate closely on design and production issues. This example reinforces the idea that, while organizational integration may facilitate interaction, practical integration may be achieved by forms other than consolidation in the same legal entity (Dyer 1997).

In the third case (Kilimanjaro), a firm offers a unique suspension design, but outsources design. In this case, we learned that the frame geometry is created internally, but the computer model is created by the manufacturer. This division of effort may allow the firm to

Table 4 **Results of Tests of Hypotheses Evaluated Independently**

Hypotheses	Number of observations in which hypothesis holds
Firms with competitively unique suspensions do design internally	12 of 15 ($p = 0.04$)
Firms with competitively unique materials processing do production internally.	3 of 3 ($p = 0.03$)
Firms which lack scale and do not have competitively unique materials processing outsource production.	10 of 10 ($p = 0.03$)
Firms employing new materials integrate design and production, either within their own firm or within a single supplier.	8 of 10 ($p = 0.23$)

P values indicate the probability that this outcome could arise randomly, assuming that the probability of a firm internalizing design is 13/23, internalizing production is 7/23, and integrating design and production is 16/23. These are the fractions reflected in the actual sample.

Table 5 **Values of Volume and Materials Variables for Each Observation**

Firm	Volume (1000s)	N Materials	Volume/ N-Materials (1000s)
Baker	300	3	100
Cannon	300	3	100
Crestone	300	2	150
Denali	300	2	150
Everest 1	300	3	100
Everest 2	300	3	100
Everest 3	300	3	100
Kilimanjaro	300	3	100
Matterhorn	300	3	100
Mitchell	50	1	50
Mont Blanc	75	2	38
Olympus 1	75	3	25
Olympus 2	75	3	25
Ranier	35	2	18
Ras Dashan	50	4	13
Shasta	13	1	13
Snowmass	13	3	4
Teton	200	2	100
Vesuvius	100	2	50
Washington	100	3	33
Whiteface 1	35	2	18
Whiteface 2	35	2	18
Whitney	13	2	7

achieve the benefits of internalized design and of outsourced production.

5.2. Why Does No One Outsource Design and Internalize Production?

We noted in Section 3 that there are four theoretical organizational forms corresponding to internalization or outsourcing of design and production. However, we observe that no firm outsources design while internalizing production. In some of our related research (Ulrich and Ellison 1999), we also observed that this was the pattern for the vast majority of manufacturers from a sample of 225 engineered, assembled goods.

In the mountain bicycle industry, we observe that only three manufacturers have a strong motive to internalize production because of unique materials processing capabilities. Absent a strong motive for internalization, the only reason to do production internally is to integrate it with an internal design activity. This suggests that internal production, in most cases, will only occur in conjunction with internal design. The exception would be the firms that compete based on their materials processing capabilities. In our sample, these firms also offered unique suspension designs and so internalized design. Interestingly, in one of these cases, the firm was very late in developing a unique suspension. It initially licensed a well-known suspension design, which is a form of design outsourcing.

Conceptually, firms that internalize production, but outsource design can be thought of as "publishers." The analogy is to book publishers, who brand (and sometimes print) the "designs" of outsiders. This organizational form is also seen in fashion and furniture, where a designer may be an independent contractor to a manufacturer. We speculate that this organizational form is competitively viable in industries where production and distribution are important competitively, but where the quality of product designs is very difficult to predict and may be based on taste or fashion. Because these conditions are rare in engineered, assembled goods, we speculate that this organizational form will also be rare, occurring only in transient cases.

5.3. Managing Conflicting Motives for Organizational Structure

An organizational design conflict arises when there is a net motive to externalize one activity, to internalize another, and to integrate the two. In the case of bicycle frames, such a situation arises when a firm wishes to develop a unique suspension design using a new material, but does not have sufficient volume to produce efficiently internally. Such a firm is faced with the possibility of either: (1) splitting design and production activities that could benefit from integration, (2) internalizing an activity that would benefit from being outsourced (most often production), or (3) outsourcing an activity that would benefit from being internalized (most often design). Several strategies may be effective in mitigating the risks associated with these compromises.

In the first case, splitting two activities that could benefit from integration results in a need for non-hierarchical mechanisms for organizational integration. Dyer (1997) explores several such mechanisms in depth. He finds that in the automobile industry, geographic proximity and the use of face-to-face meetings between members of cooperating but separate organizations can be effective in integrating their activities. In some cases, it may be possible to locate people from two different organizations in the same workspace in order to minimize coordination costs and maximize the probability of joint problem solving. In the case of product design, such co-location does not present substantial geographic asset specificity, because it is easy for the designer to simply move back to his/her home organization should the relationship fail. Adler (1995) reviews specific coordination mechanisms for design and production which include producibility design reviews and joint teams, which may also be effective. Agency issues may be minimized when there are repeated exchanges over a long time period. We observe that all of these mechanisms are used by Everest in its relationships with its frame supplier.

In the second case, internalizing an activity that would benefit from being outsourced poses the threat of substantially increased costs and/or financial risk. In the bicycle industry, the most common example of this compromise is internalizing production when the firm does not have substantial volume. The cost and financial risks, in this case, are presumably outweighed by the benefits of integrating design and production, and/or of internalizing design. In such situations, one mitigating approach may be to adapt the product's design and associated production process to accentuate and further exploit the potential benefits of integration and/or internalization. For example, in bicycle frames, such strategies could include high levels of customization (e.g., in sizes or colors) or seeking processing innovations that may offer a unique competitive advantage.

In the third case, outsourcing an activity that would benefit from internalization presents risks of losing (or not developing) a valuable capability. These risks are discussed by Anderson and Parker (2002). In the bicycle domain, such situations arise when a firm wishes to offer a unique product design, but outsources design to its supplier because of the need to integrate design and production. Contractual strategies are often attempted in these situations and may be partially effective. These include non-disclosure agreements, non-compete agreements, and assignment of patent rights. However, suppliers are unlikely to enter into strict contractual agreements when there is substantial demand for their services and productive capacity. A more effective strategy may be to separate conceptual design and system-level design from detail design. In the case of frame design, much of the interaction between design and production is at a detailed level and concerns issues such as tubing thicknesses, joint angles, and location of fixturing points. To the extent that the conceptual and system design can be done by the manufacturer, while allowing the supplier to perform detailed design, some of the risks of outsourcing design may be mitigated. This appears to be one of the strategies pursued by Kilimanjaro.

5.4. Complex Products and Systems

Our discussion has focused on relatively simple networks of activities such as those associated with the design and production of a single product-specific component such as a bicycle frame. Even in this simple setting organizational challenges arise frequently because of the conflicting motives for outsourcing, internalizing, and/or integration. These challenges are even more pronounced for complex systems comprising dozens of subsystems and thousands of components, and for families of products comprising many variants. In such settings, architectural choices become prominent (Ulrich 1995) and the problem of platform optimization emerges (Gupta and Krishnan 1999). The complexity of the production process provides additional decision problems related to internalizing or outsourcing process and equipment design (Fine and Whitney 1996).

5.5. Dynamics and Path Dependence

The factors that motivate a particular organizational form are dynamic. As a result, organizations are likely to be compelled to adapt over time. In the bicycle industry, theory predicts that a dominant suspension design will emerge (Abernathy and Utterback 1978). When this occurs, firms that have internalized design will need to innovate around some new element of the product or in a new product category, or may benefit from outsourcing design to suppliers. What is a new material today will be a mature material in 10 years. As materials mature, design rules will emerge, which will allow design and production to be disintegrated. This will provide new opportunities for suppliers and new challenges for integrated manufacturers. What is a distinctive materials processing capability today may some day be commonplace. Under these conditions, firms that have internalized production in order to develop unique materials processing capabilities will face increasing pressure to allow increasingly capable suppliers to provide productive capacity.

Although we present the factors associated with internalization and integration as deterministic, the dynamics are somewhat path dependent. A firm that at one point, for good reason, developed a substantial internal production capability will be less likely to outsource its production than a new entrant even if the motives for outsourcing are quite compelling. This is partially due to organizational inertia, but also because of very real commitments, especially in smaller privately held companies, to an established work force.

There may also be path dependence in design. Cohen and Levinthal (1990) argue that relevant internal R&D activities increase a firms "absorbtive capacity"—its ability to recognize and acquire relevant outside technological information. This suggests that if a firm sheds its design activities completely, it may fail to recognize technological opportunities in the future.

6. Summary

We have argued that there is a useful distinction between motives for internalizing an activity within the organization of the manufacturer, and the motives for integrating two activities into the same organizational entity, which may or may not be the manufacturer. Given this distinction, decisions about internalizing design and internalizing production cannot be fully understood in isolation. They are joint decisions because of the motives for integration of design and production. For the design and production of product-specific components, four organizational forms are possible in theory: (1) internal design, internal production; (2) internal design, external production; (3) external design, internal production; and (4) external design, external production. We argue that "Make" and "Buy" do not reflect the distinctions among these categories. For bicycle frames, form (4)—external design with internal production—does not happen in practice. We speculate that this form is rare in general for engineered goods.

We argue that design and production activities can be disintegrated when production processes have matured to the point where there are explicit design rules that express the constraints and capabilities of the production process. A potential organizational conflict arises when there is a high need to integrate two activities, but a strong motive to outsource one of the activities and internalize the other. Several mechanisms may be useful in mitigating potential weaknesses in the organizational compromises that result from such situations, including the use of non-hierarchical mechanisms for organizational integration and the decomposition of design tasks into conceptual design and design-for-manufacturing, which would be then split across two organizations.

Acknowledgments

This article evolved from a working paper written in 1998 (Ulrich and Ellison 1998). Taylor Randall contributed substantially to the original data collection effort. We are grateful for the helpful comments from the associate editor and three reviewers.

References

Abernathy, W. J., J. M. Utterback. 1978. Patterns of innovation in technology. *Technology Review* **80**(7) 40–47.

Adler, P. S. 1995. Interdepartmental interdependence and coordination: The case of design/manufacturing interface. *Organization Science* **6**(2) 147–167.

Alchian, A., H. Demsetz. 1972. Production, information costs, and economic organization. *American Economic Review* **62** 777–795.

Anderson, E. G., G. G. Parker. 2002. The effect of learning on the make/buy decision. *Production and Operations Management* **11**(3).

Asanuma, B. 1985. The contractual framework for parts supply in the Japanese automotive industry. *Japanese Economic Studies* (Summer) 55–78.

Asanuma, B. 1989. Manufacturer supplier relationships in Japan and the concept of relation-specific skills. *Journal of Japanese and International Economics* 55–78.

Balakrishnan, S., B. Wernerfelt. 1986. Technical change, competition and vertical integration. *Strategic Management Journal* **7**(4) 347–359.

Baldwin, C. Y., K. B. Clark. 1999. *Design rules: The power of modularity.* MIT Press, Cambridge, Massachusetts.

Clark, K. B. 1989. Project scope and project performance: The effect of parts strategy and supplier involvement on product development. *Management Science* **35** 1247–1263.

Clark, K. B., T. Fujimoto. 1991. *Product development performance.* Harvard Business School Press, Boston, Massachusetts.

Coase, Ronald. 1937. The nature of the firm. *Econometrica* **4** 386–405.

Cohen, W. M., D. A. Levinthal. 1990. Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly* **35**(1) 128–152.

Crocker, K. J., S. E. Masten. 1988. Mitigating contractual hazards: Unilateral options and contract length. *RAND Journal of Economics* **19** 327–343.

Dyer, J. H. 1997. Effective interfirm collaboration: How firms minimize transaction costs and maximize transaction value. *Strategic Management Journal* **18**(7) 535–556.

Fine, C. H., D. E. Whitney. 1996. Is the make-buy decision process a core competence? Working Paper, MIT Center for Technology, Policy, and Industrial Development.

Fine, C. H. 1999. *Clockspeed: Winning industry control in the age of temporary advantage.* Perseus Books, Reading, Massachusetts.

Fine, C. H. 2000. Clockspeed-based strategies for supply chain design. *Production and Operations Management* **9**(3) 213–221.

Galbraith, J. R. 1974. Organization design: An information processing view. *Interfaces* **4**(3) 28–36.

Gupta, S., V. Krishnan. 1999. Integrated component and supplier selection for a product family. *Production and Operations Management* **8**(2) 163–181.

Harrigan, K. R. 1986. Matching vertical integration strategies to competitive conditions. *Strategic Management Journal* **7**(6) 535–555.

Holmstrom, B., P. Milgrom. 1991. Multi-task principal-agent problems: Incentive contracts, asset ownership and job design. *Journal of Law, Economics and Organization* **7**.

Hopp, W. J., M. L. Spearman. 1996. *Factory physics: Foundations of manufacturing management.* Irwin, Chicago, Illinois.

Iansiti, M., K. B. Clark. 1994. Integration and dynamic capability: Evidence from product development in automobiles and mainframe computers. *Industrial and Corporate Change* **3**(3).

Iansiti, M. 1998. *Technology integration: Making critical choices in a dynamic world.* Harvard Business School Press, Boston, Massachusetts.

K2 Inc. 2003. Annual Report (NYSE: KTO).

Kogut, B., U. Zander. 1986. What firms do? Coordination, identity, and learning. *Organization Science* **7**(5) 502–518.

Krishan, V., S. D. Eppinger, D. E. Whitney. 1997. A model-based framework to overlap product development activities. *Management Science* **43**(4) 437–451.

Lewis, T. R., D. E. M. Sappington. 1991. Technological change and the boundaries of the firm. *The American Economic Review* **81** 887–900.

Liker, J. L., R. R. Kamath, S. N. Wasti, M. Nagamachi. 1996. Supplier involvement in automotive component design: Are there really large US Japan differences? *Research Policy* **25** 59–89.

Loch, C., C. Terwiesch. 1998. Communication and uncertainty in concurrent engineering. *Management Science* **44**(8).

MacDonald, J. M. 1985. Market exchange or vertical integration: An empirical analysis. *The Review of Economics and Statistics* **LXVII**(2) 327–331.

Mahoney, J. T. 1992. The Choice of Organizational Form: Vertical financial ownership versus other methods of vertical integration. *Strategic Management Journal* **13** 559–584.

Masten, S. E. 1984. The organization of production: Evidence from the aerospace industry. *Journal of Law and Economics* **27** 403–417.

Masten, S. E., J. W. Meehan Jr.[/exclude], E. A. Snyder. 1991. The costs of organization. *Journal of Law, Economics, and Organization* **7**(1) 1–25.

Monteverde, K., D. J. Teece. 1982a. Supplier switching costs and vertical integration in the automobile industry. *Bell Journal of Economics* **13** 206–213.

Monteverde, K., D. J. Teece. 1982b. Appropriable rents and quasi-vertical integration. *Journal of Law and Economics* 25 321–328.

Monteverde, K. 1995. Technical dialog as an incentive for vertical integration in the semiconductor industry. *Management Science* **41**(10) 1624–1638.

Novak, S., S. Eppinger. 2001. Sourcing by design: Product complexity and the supply chain. *Management Science* **47**(1) 189–204.

Ouchi, W. G. 1980. Markets, hierarchies, and clans. *Administrative Science Quarterly* **25** 124–141.

Parker, G. G., E. G. Anderson. 2002. From buyer to integrator: The transformation of the supply chain manager in the vertically disintegrating firm. *Production and Operations Management* **11**(1) 000–000.

Pisano, G. P. 1990. The R&D boundaries of the firm: An empirical analysis. *Administrative Science Quarterly* **35** 153–176.

Smith, A. 1999. Wealth of Nations. Penguin Books (London published 1999), 1776.

Teece, D. J. 1986. Profiting from technological innovation. *Research Policy* **15**(6) 285–305, 1986.

Teece, D. J., G. Pisano, A. Shuen. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal* **18**(7) 509–533.

Thompson, G. V. 1954. Intercompany technical standardization in the early American Automobile Industry. *Journal of Economic History* **24**(1) 1–20.

Thompson, J. D. 1967. *Organizations in action.* McGraw-Hill, New York, New York.

Tirole, J. 2001. *The theory of industrial organization.* The MIT Press, Cambridge, Massachusetts.

Ulrich, K. T., T. Randall, M. Fisher, D. Reibstein. 1999. Managing product variety: A study of the bicycle industry in *Managing Product Variety.* Teck Ho and Chris Tang (eds.), Kluwer Academic Publishers, Boston, Massachusetts.

Ulrich, K. T., D. J. Ellison. 1998. Beyond make-buy: Internalization and integration of design and production. Working Paper, Department of Operations and Information Management, The Wharton School, Philadelphia, Pennsylvania.

Ulrich, K. T., D. J. Ellison. 1999. Holistic customer requirements and the design-select decision. *Management Science* **45**(5) 641–658.

Ulrich, K. T., S. D. Eppinger. 2004. *Product design and development*, 3rd edition. McGraw-Hill, New York, New York.

Ulrich, K. T. 1995. The role of product architecture in the manufacturing firm. *Research Policy* **24** 419–440.

Walker, G., D. Weber. 1987. Supplier competition, uncertainty, and make-or-buy decisions. *Academy of Management Journal* **30**(3) 589–596.

Williamson, O. E. *Markets and hierarchies.* 1975. The Free Press, New York, New York.

Williamson, O. E. 1985. *The Economic institutions of capitalism.* The Free Press, New York, New York.

Zenger, T. R. 1994. Explaining organizational diseconomies of scale in R&D: Agency problems and the allocation of engineering talent, ideas, and effort by firm size. *Management Science* **40**(6) 708–729.