Product Variety, Supply Chain Structure, and Firm Performance: Analysis of the U.S. Bicycle Industry

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Using data from the U.S. bicycle industry, we examine the relation among product variety, supply chain structure, and firm performance. Variety imposes two types of costs on a supply chain: *production costs* and *market mediation costs*. Production costs include, among other costs, the incremental fixed investments associated with providing additional product variants. Market mediation costs arise because of uncertainty in product demand created by variety. In the presence of demand uncertainty, precisely matching supply with demand is difficult. Market mediation costs include the variety-related inventory holding costs, product mark-down costs occurring when supply exceeds demand, and the costs of lost sales occurring when demand exceeds supply. We analyze product variety at the product attribute level, noting that the relative impact of variety on production and market mediation costs depends to a large extent on the attribute underlying the variety. That is, some types of variety incur high production costs and some types of variety incur high market mediation costs. We characterize supply chain structure by the degree to which production facilities are scale-efficient and by the distance of the production facility from the target market. We hypothesize that firms with scale-efficient production (i.e., high-volume firms) will offer types of variety associated with high production costs, and firms with local production will offer types of variety associated with high market mediation costs. This hypothesis implies that there is a coherent way to match product variety with supply chain structure. Empirical results suggest that firms which match supply chain structure to the type of product variety they offer outperform firms which fail to match such choices.

(*Product Variety; Supply Chain Structure; Firm Performance*)

1. Introduction

Using data from the U.S. bicycle industry, this paper examines two basic research questions: 1) How does product variety relate to supply chain structure? and 2) how does matching product variety to supply chain structure affect firm performance?

We define product variety as the number of different versions of a product offered by a firm at a single point in time. We analyzed differences across products at the product attribute level, a common practice in the consumer product literature where complete products are modeled as bundles of consumer attributes (Green and Srinivasan 1978). Variety within a product line arises by varying the values of attributes from one product to another. The presence of variety increases two basic categories of costs within supply chains: production costs (Stalk and Hout 1990, Cooper 1990) and market mediation costs (Fisher 1996). Production costs include direct materials, labor, manufacturing overhead, and process technology investments. Market mediation costs arise because of uncertainty in product demand. In the presence of demand uncertainty, precisely matching supply with demand is difficult. Market mediation

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costs include the inventory holding costs and product mark-down costs occurring when supply exceeds demand, and the costs of lost sales when demand exceeds supply.

While adding variety to a product line increases both production costs and market mediation costs, we note that different types of variety have different relative influences on production costs and market mediation costs, depending on the product attributes which underlie that variety. Hence, the association between product variety and supply chain structure depends on the relative impact of variation in each product attribute on production costs and market mediation costs. For conceptual clarity, we distinguish between two types of variety: *production-dominant variety* and *mediation-dominant variety*. Variety is production-dominant if the increase in production costs associated with increased variety outweighs the increase in market mediation costs. For example, variation in body styles of an automobile is production dominant because of the huge tooling investments associated with creating that variety. Conversely, variety is mediation-dominant if the increase in mediation costs associated with increased variety outweighs the increase in production costs. For example, variation in trim colors of an automobile is mediation dominant because the impact of additional colors on production costs is minimal, while the impact on inventory and stock-out costs is substantial. Production-dominant variety typically requires substantial investments in fixed costs for each variant. Mediation-dominant variety is often associated with a high degree of forecast difficulty.

Supply chain structure also influences the magnitude of production and market mediation costs. We characterize supply chain structure along two fundamental dimensions: (1) the distance of production facilities from a target market, and (2) the degree to which production facilities reach minimum efficient scale. Structural alternatives created by these dimensions often present economic tradeoffs associated with production and market mediation costs. For example, firms choosing to maintain efficient scale in production facilities will reduce production costs. However, to attain scale, a firm might be required to pool production volume across disparate geographic markets into one facility (MacCormack et al. 1994). The pooling of volume increases the distance from regional markets, and hence replenishment lead times, making the firm more vulnerable to higher demand uncertainty, and resulting in higher mediation costs (Hadley and Whitin 1963, Stevenson 1996).

We note that the decision to produce in-house or to outsource often creates such tradeoffs. A firm seeking scale economies might outsource production to a third party (e.g., a large supplier to several competing firms) located outside the target market, creating a compromise between production costs and market mediation costs. In other circumstances, outsourcing mitigates such tradeoffs. A firm lacking scale might be able to outsource production to a scale-efficient facility located within the target market. This eliminates the long lead times associated with higher market mediation costs, while maintaining scale efficiency in production.

We hypothesize that higher levels of production-dominant variety will be positively associated with firms organizing production to attain scale economies, and that higher levels of mediation-dominant variety will be associated with firms locating production close to customers in the target market. This is because firms will seek to match scale economies with production-dominant variety and will seek to match the short replenishment lead-time of localized production with mediation-dominant variety.

This theory implies that there are coherent matches between product variety and supply chain structure. This is consistent with observations by researchers in operations management and strategy who posit that firm performance is, in part, a function of coherent alignment between supply chain structure and product variety (Shank and Govindarajan 1993, Hayes and Wheelwright 1984, Nath and Sudharshan 1994, Fisher 1996, Bozarth and Edwards 1997). We test and find support for the hypothesis that those firms which coherently match increased production-dominant variety with scale-efficient production or increased mediation-dominant variety with localized production outperform those firms which fail to match variety and supply chain strategies.

The study differs from existing research on product variety in two important ways. First, previous empirical research focuses on the association between product variety and costs in individual plants. (See for example Foster and Gupta 1990, Anderson 1995, Ittner and MacDuffie 1995, MacDuffie et al. 1996, Ittner et al. 1997, Fisher and Ittner 1999.) We empirically examine the relation between the costs of product variety and the larger structure of the supply chain. Second, most studies ignore the association between product variety and firm profitability, despite the fact that marketing researchers claim that the revenue gains from a broader product line may exceed the costs. (For a review of this literature see Lancaster 1990, and Kekre and Srinivasan 1990.) By examining performance measures such as return on sales and return on assets, we explicitly examine the cost and revenue tradeoffs associated with product variety.

The paper proceeds as follows. In §2, we review the literature to motivate the primary hypotheses of the paper. In §3, we describe the bicycle industry and data sources. Section 4 discusses the statistical methodology and measures used to test hypotheses. We present results in §5. Section 6 contains concluding remarks.

2. Hypothesis Development

Supply Chain Structure and Supply Chain Costs

Our characterization of supply chain structure using the dimensions of distance and scale is common in operations literature. Models of location use these structural dimensions to examine tradeoffs between the fixed costs of opening new plants verses the transportation costs from more centrally located facilities. (See Francis 1974 or Krarup and Pruzan 1983 for a review). Cohen and Moon (1990) specifically analyze tradeoffs between scale economies in plants and transportation costs to consumers. Skinner (1974) and Miller and Vollman (1985) examine plant scale issues by analyzing tradeoffs between low production costs and high overhead costs of large plants, and the higher unit costs, but lower overhead costs of smaller focused factories.

We examine tradeoffs between production costs and market mediation costs which may arise as firms choose the scale and location of production facilities and explicitly examine the role of product variety within the decision. Production costs include direct materials, labor, costs for design and tooling, and manufacturing overhead. Market mediation costs arise as firms attempt to match supply with demand. These costs include inventory holding costs occurring when supply exceeds demand, and the cost of lost sales occurring when demand exceeds supply. Production cost advantages manifest in lower average unit costs accrue to firms via economies of scale. Economies of scale accompanying higher production volumes arise through quantity discounts in purchasing, labor efficiency gains through learning, and shifts from labor-intensive, high-variable-cost production processes to capital-intensive, lower-variable-cost processes. In order to achieve economies of scale, a firm has incentive to aggregate production up to the point that minimum efficient scale is reached. Often, geographic distance from regional markets is a by-product of aggregated production. The distance creates longer replenishment lead times and forecast horizons. Long lead times and forecast horizons increase exposure to demand uncertainty that increases market mediation costs (Nahmias 1997, Hadley and Whiten 1963). In order to minimize market mediation costs, a firm has incentive to build plants locally at a cost of reduced scale.

Two important caveats to the location and scale tradeoffs merit discussion. First, a firm with the ability to build scale-efficient plants in each regional market or to outsource production to scale-efficient plants in each regional market does not face cost tradeoffs. However, in industries as diverse as computers and bicycles, factors such as the small size of regional markets and the competitive dynamics limiting firm size prohibit firms from structuring supply chains to avoid production and market mediation cost tradeoffs. For example, in notebook computers, Dell currently chooses a decentralized strategy by locating assembly plants within each regional market while Acer, located in Taiwan, acts as a scale-efficient supplier to many different brands serving regional markets.

Second, under several structural conditions, the aggregation process that builds economies of scale also mitigates market mediation costs through pooling of finished goods inventory (Eppen 1979). These conditions include (1) product characteristics are not specific to each regional market, (2) holding inventory at the scale-efficient location, and (3) savings from pooled inventory outweighing the potential lost sales due to longer response time. When these conditions exist, the cost tradeoffs between scale and location are mitigated.

Role of Outsourcing

While operations models use location and scale as dimensions of supply chain structure, economists characterize supply chain structure by the degree of vertical integration or degree of outsourcing. Factors influencing the outsourcing decision commonly cited in the literature include asset specificity and threat of hold-up, preservation/development of distinctive capabilities, task uncertainty because of exogenous factors, competition among suppliers, access to capabilities, and external economies of scale. (See Mahoney 1992, Ellison and Ulrich 1999, and Fine 1998 for a comprehensive discussion of why firms outsource.)

In our framework, the desire to acquire economies of scale through outsourcing can both ameliorate and exacerbate the cost tradeoffs associated with production and market mediation costs. For example, a firm seeking the benefits of scale might choose to outsource production to a scale-efficient firm. The effect of the sourcing decision on supply chain costs depends on the location of the scale-efficient facility. If the scale-efficient firm is located outside the target market, the firm will incur increased market mediation costs in return for lower production costs. Conversely, a firm located outside its target market might outsource production to a scale-efficient firm located within the target market, eliminating both production and market mediation costs. The net effect of sourcing on the structure of a supply chain will depend to a great degree on the geographic structure of a given industry. Where do scale-efficient suppliers reside?[1]

[1] Sorenson and Audia (2000) provide an interesting discussion and examples of geographic structure in industries. They assert nearly all industries exhibit geographic concentration.

Costs of Product Variety and Supply Chain Structure

Increasing product variety within a supply chain increases both production costs (Stalk and Hout 1990, Cooper 1990) and market mediation costs (Fisher 1996). Product variety exacerbates production costs when volume is split among multiple products such that quantity discounts in purchasing are unattainable, efficiency gains of learning are delayed as resources alternate focus among multiple products, and investments in scale-efficient production technology are not justified. In sum, the higher variety can increase the volume required to reach minimum efficient scale. Similarly, variety acts to intensify demand uncertainty leading to increased market mediation costs. For a given replenishment lead time, a firm offering two variants will carry more finished goods inventory than a firm with one variant, because of increased uncertainty surrounding the demand forecast. (See Eppen 1979 for an example of this phenomena.) To provide higher variety at lower market mediation costs, a firm has an incentive to reduce lead times by localizing production.

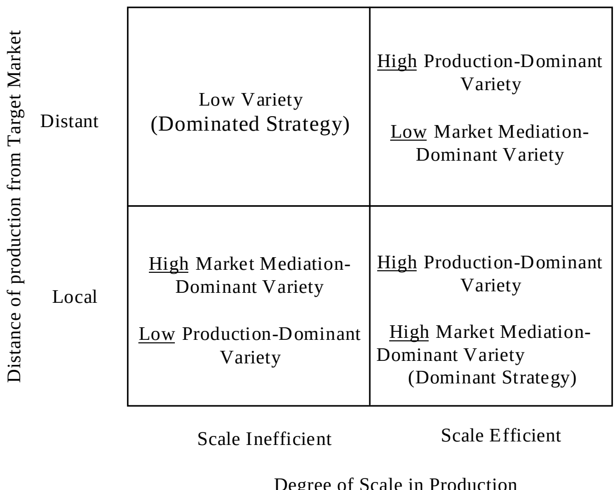
Attribute-Level Variety and Variety Costs

We consider a product to be a bundle of consumer attributes, as is customary in marketing research (Green and Srinivasan 1978). For example, a bicycle has four primary attributes: frame material, frame geometry/size, frame color, and components. Variation with respect to different attributes has a different relative effect on production and market mediation costs. In bicycles, variation in frame materials affects production costs to a higher extent than market mediation costs, while color variety affects market mediation costs to a greater extent than production costs. These differential cost effects of product attributes allow firms to resolve cost and location tradeoffs by matching the types of product variety they offer with their supply chain structure.

Hypotheses

Our theory associates higher variety with higher production costs and higher market mediation costs, but also argues that the relative sensitivity of these costs to product variety will vary by product

Figure 1 Degree of Scale in Production



attribute. Offering variety that increases production costs should be associated with a choice of scale-efficient production. On the other hand, offering variety that increases market mediation costs should be associated with a choice of localized production to reduce unnecessary exposure to demand uncertainty (i.e., minimizing lead time). These arguments form the bases for our first hypothesis stated below and depicted in Figure 1. We emphasize the associative, rather than causal, nature of these hypotheses.

Hypothesis 1. *A. Firms using scale-efficient production processes will have higher levels of production-dominant variety than firms using scale-inefficient processes.*

B. Firms with plants located within target markets will have higher levels of market mediation-dominant variety than firms located away from the target market.

Researchers in strategy and operations management emphasize that firm performance is, in part, a function of coherent alignment among structural elements of an organization (Hayes and Wheelwright 1984, Shank and Govindarajan 1993, Nath and Sudharshan 1994, Fisher 1996, Bozarth and Edwards 1997). Consistent with these assertions, Hypothesis 1 suggests that firm profitability depends on the proper match of location and type of product variety. Figure 1 depicts the variety and location decisions that coherently match and those that do not for both production-dominant variety and mediation-dominant variety.

We note that the distant-scale-inefficient strategy is dominated by other strategies. A firm operating in this structure suffers both production and market mediation costs disadvantages of variety. We note that a scale-efficient-local strategy is a dominant strategy. When this alternative is available, firms with these capabilities can offer any type of variety without suffering location or scale penalties. In the absence of the dominant strategic alternative, firms may either choose to pursue high-variety or low-variety strategies, but for the profit-maximizing firm, these strategies must be matched with the supply chain structure which minimizes the cost of pursuing that strategy. Consider production-dominant variety as an example. If the firm pursues high production-dominant variety, costs are minimized by aggregating production in a distant location, since the benefits of economies of scale are greater than the penalty of long lead time. If a firm pursues low production-dominant variety, the diseconomies of scale associated with high variety are absent, eliminating the incentive to aggregate to minimize production costs. Given this, the firm offering low levels of production-dominant variety has incentive to localize production in order to eliminate market mediation costs associated with the longer replenishment lead times and aggregation. Furthermore, such a firm may choose to offer higher variety with respect to a mediation-dominant attribute, and thus would benefit from local production. In this case, the profit maximizing firm minimizes the cost of delivering the production-dominant attribute by offering low variety along that dimension. Similar matching arguments apply to the mediation-dominant variety case. (Note that these arguments are framed as firms making joint decisions about product variety and supply chain structure. We are arguing that profit maximizing firms *match* product variety and supply chain structure, but we are not arguing for a particular direction of causality.)

Firms failing to match variety and location are subject to higher costs or lower revenues. In the production-dominant variety case, choosing a scale-inefficient location and high production-dominant variety results in higher production costs than if a scale-efficient location were chosen. Similarly, choosing a scale-efficient location and low variety results in a lost revenue opportunity of higher variety, which could be cheaply supplied from the location. Similar mismatch arguments apply to the mediation-dominant variety case. Taken together, the cost and revenue implications of matching and mismatching suggest that firms correctly matching variety with location will outperform those that fail to match.

HYPOTHESIS 2. *Firms matching production-dominant variety with scale-efficient production and mediation-dominant variety with local production outperform firms which fail to make such matches.*

3. Industry Context and Data Sources

Industry Context

The 100–130 million unit world bicycle market can be divided into low-end bicycles (below $200) and high-end bicycles (over $200). Low-end bicycles include children's bicycles and bicycles used for basic transportation. High-end bicycles are primarily adult bicycles used for rigorous recreational activities. Our analysis focuses on bicycle manufacturers in the "over-$200" portion of the bicycle market. By "manufacturer," we refer to the brand owner. The brand owner may or may not literally produce its products. All manufacturers are responsible for making product line decisions and selling/promoting bicycles. With few exceptions, manufacturers in this segment do not serve global markets, but serve national and regional markets (North America, Europe or Asia).[2] However, manufacturers serving the U.S. bicycle market may locate production within the U.S. or in Asia, even though they do not sell products outside the U.S. Because of the substantial differences in markets across regions, we focus on the association between product variety and production location decisions made to serve one regional market, the United States.

The United States bicycle market constitutes about 10% of the 100–130 million units sold globally. The over-$200 segment accounts for 2 to 3 million units per year in the United States. Ninety-five percent of all bicycles priced above $200 belong to approximately 82 manufacturers, the vast majority of which distribute bicycles through independent bicycle dealers (IBDs). As of 1997, there were approximately 6,000 IBDs in the U.S., with 1,500 dealers accounting for 60% 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% in 1985 to 56% in 1997.

We focus on the bicycle industry for several reasons:

- Supply chains in this industry exhibit interesting structure and variation, but are not so complex as to prohibit measurement and comparison. For example, while companies look for global sources of supply, the target market is primarily the United States. The data indicate that 85% of company sales occur in the U.S. market. This fact facilitates more reliable measures of supply chain structure and supply chain performance.
- The product is understandable and easily decomposed into relevant consumer attributes.
- Other variables mitigating the cost of variety, such as flexible production technology and degree of product modularity, are similar across firms, making the location decision critical in managing supply chain costs.

We focus on the over-$200 portion of the bicycle market because the large number of competitors allows for substantial variation in strategies. In contrast, the below-$200 market is dominated by several large manufacturers which distribute through large retail stores (e.g., Huffy and Roadmaster distribute through Wal-mart, K-mart, and Toys R' Us).

Production Process and Product Variety

Bicycle production requires three generic production tasks: frame fabrication, frame painting, and bicycle assembly. These tasks must be performed in this order. Frame fabrication consists of cutting and welding tubes into unfinished frames.[3] Frame painting

[2] Giant Manufacturing of Taiwan is one of the first companies attempting to build a global brand. U.S. companies such as GT, Trek, and Cannondale are following suit.

[3] The frame production process will differ by the type of frame material being processed. With most metals, tubing is measured, cut then welded into a frame geometry of a specific size. With carbon fiber, molding processes are used.

Table 1 Incremental Effect of Attribute Variety on Production and Market Mediation Costs

	Expert Assessment		Related Information	
Variation in:	Effect on Production Costs	Effect on Market Mediation Costs	Effect on Production Costs (Fixed Investment)	Effect on Market Mediation Costs (Available Choices)
Materials	High	Low	$ 1 MM to $1.5 MM	4
Geometry/size	Low	Medium	$5,000 to $10,000	50
Components	Low	Medium	$0	15
Colors	Low	High	$1,000	1,000+

consists of adding color to frames, applying decals, and a final clear finish. In assembly, components such as wheels, tires, suspension, and drive trains are attached to the finished frame.

Along with price, consumers evaluate differences in bicycles with respect to four different attributes: frame material, frame geometry/size, frame color, and components (including derailleurs, suspension and wheels).

A consumer might compare a green, steel (frame color and frame material), large mountain bike (frame geometry/size), with Shimano XT derailleurs (components) against a blue, aluminum, large mountain bike with Shimano LX derailleurs. An attribute level refers to a variant of a particular attribute. Levels of the frame material attribute include steel, aluminum, titanium, and carbon fiber, with further variants of each of these categories possible. Firms choose the combination of attribute levels to position their products in the target market. For example, Specialized uses 8 different materials in its 210 bicycles, while Cannondale uses a single material in its 196 bicycles. On the other hand, Cannondale's products come in 60 different geometry/size combinations, while Specialized's bicycles come in only 36 geometry/size combinations. Each product attribute maps to a specific production process; materials and geometry/size to frame fabrication, color to frame painting, and components to assembly.

We decompose a product into its consumer attributes in order to examine the differential effects of variety on production and market mediation costs. Using a panel of industry experts, we estimated the relative effect of variation in each bicycle attribute on production and market mediation costs.[4] In the case of production costs, we asked experts to rate the relative cost of offering an additional level of a product attribute (High, Medium, or Low). In the case of mediation costs, we asked experts to rate to the relative forecast uncertainty and sales risk associated with offering an additional level of each product attribute (High, Medium, or Low). Columns 1 and 2 of Table 1 list the average assessments of production and mediation costs for variation in each attribute. As corroborative evidence to our experts' opinions on production costs, in Column 3 we provide estimates gathered from plant tours and publicly available sources of the fixed production investments required to add another level of each bicycle attribute.[5] In Column 4, we list the superset of levels available to consumers for each attribute by all manufacturers in the market. For example, a customer may choose from four different materials, but thousands of different colors. This data is generally supportive of expert opinion, in that we expect an inverse correlation between variety offered and fixed production investment; we also expect that the attributes with extremely high variety (e.g., color) are likely to be those associated with fashion or taste, and therefore harder to predict.

[4] Our panel of experts in included executives from seven bicycle companies. All executives were at the vice-president level or higher, and were familiar with their company's supply chain management function.

[5] Cost estimates are based on an assembly line production system. The incremental variety investment for job shops in materials, geometry/size, paint and components are $10,000, $300, $100, and $0 respectively. However, job shop variable labor costs are 2 to 3 times higher than those of assembly lines.

We note marked variation in the relative magnitude of production and market mediation costs across attributes. The material and color attributes are two striking examples. The production costs associated with each additional material are high ($1,000,000 to $1,500,000 investment per material), while the fixed production costs associated with each additional color are low ($1,000 per color).[6] On the other hand, the demand uncertainty surrounding color variants is high (thousands of choices), whereas the demand uncertainty associated with materials is low (4 choices). We find a simple classification of attributes useful. If the production costs associated with adding a particular attribute are much larger than the mediation costs, then the attribute is *production-dominant*. If the mediation costs associated with adding a particular attribute are much higher than the production costs, the attribute is *mediation-dominant*. In the case of bicycles, we consider materials variety to be production-dominant and colors variety to be mediation-dominant. The classification of component and geometry/size variety is less striking, but these attributes are nevertheless mediation-dominant. From the analysis, we develop expectations about the association between scale-efficient production, location, and variety. We anticipate higher materials variety to be associated with scale efficient production and higher levels of geometry/size, color, and component variety to be associated with local production. The several processes required to build a bicycle need not be located in the same place, so firms can decide the structural configuration of each task. However, we note that the frame fabrication location decision affects both a production dominant attribute (materials) and a mediation-dominant attribute (geometry/size).

[6] Differences in production costs are due to the basic cost of the process technology and its underlying flexibility. A separate production process is required for each material. For instance, while steel and aluminum are both welded, the heat from welding destroys the strength of aluminum. Aluminum bikes must therefore pass through a heat treating process to restore strength. Molding or bonding, not welding, is the basic process for carbon fiber frames. Variation in geometry/size requires investment in new jigs to hold tubes while welding. Paint booths are equipped with relatively inexpensive interchangeable paint pots with a pot dedicated to each color. Assembly processes are fully manual and therefore require essentially no incremental investment for additional component variety.

Location of Production

U.S. manufacturers typically consider two production location options: (1) locate within the U.S. and (2) locate in Asia (primarily Taiwan). The median replenishment lead time for firms locating in Asia is 90 days, while the median replenishment lead time for firms in the U.S. is 34.5 days. With few exceptions, a decision to locate production in Asia includes outsourcing to a third-party supplier. Often, multiple "manufacturers" share the same production facility. For example, Giant, A-pro, Kinesis, and CBC are all large Asian bicycle producers. With the exception of Giant, these contract producers do not market their own brands in the United States. In 1997, Giant produced bicycles for its own brand, as well as other U.S. brands including Univega, Specialized, Trek, and Gary Fisher. A-Pro produced bicycles for Marin, Voodoo, Haro, Raleigh, Research Dynamics, and Parkpre (Gamstetter 1996).

Scale-Efficient Production

Independent studies of scale within the industry suggest that plants reach minimum efficient scale between 150,000–200,000 units of annual production (Mody et al. 1991). These scale estimates assume a plant produces one basic frame material—steel, aluminum, titanium, carbon fiber. Our observations suggest that to be scale efficient in multiple materials requires an additional 150,000–200,000 units of production volume per material. Since four basic materials exist, a firm would need a facility with 600,000–800,000 units of production volume to be completely scale efficient. Thus, we define scale efficient production as production using a facility over 600,000 units per year. Volume of this magnitude would indicate a firm's ability to produce multiple materials at scale-efficient costs. Public sources indicate that production volumes associated with Asian facilities typically run in the millions of units per year while U.S. plants do not produce enough units annually to reach minimum efficient scale in multiple materials. We note however that several U.S. plants have reached efficient scale in a single material. The implications of this observation will be discussed further in the paper.

Finally, in the hypothesis development, we noted several circumstances where firms might centralize production and thereby reduce market-mediation costs. Those circumstances do not hold in this case. We observe that firms do not hold finished goods inventory in Asian plants. Furthermore, the products produced at a single location are both company- and market-specific, so that the pooling benefits of inventory are absent.

Data Sources

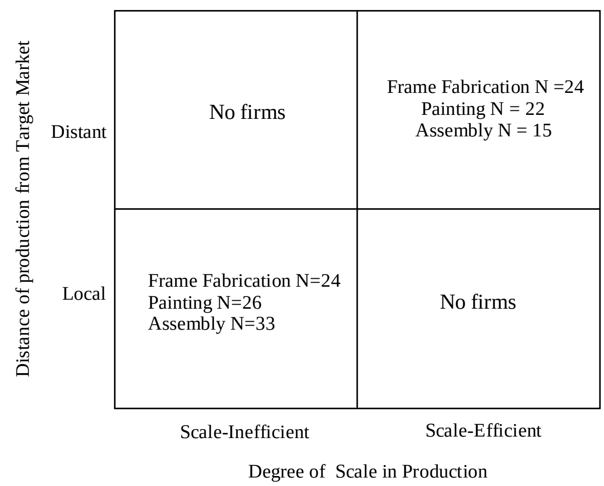
We obtained data for the 1997 sales year from two sources: (1) the annual industry buyers' guide for 1997 and (2) a survey instrument. The annual industry buyers' guide provides a detailed list of bicycle brands, products, and product specifications. The buyers' guide is used as a source for all data on product variety. The survey was used to collect data on supply chain structure. With few exceptions, there is a one-to-one match between brands and companies. We surveyed 82 companies listed in the industry buyers' guide. These firms account for approximately 95% of all firms in the market. For 10 firms, we conducted comprehensive interviews or visits to gather data and formulate a questionnaire. Questionnaires were sent to the president, manufacturing manager, or marketing manager of the remaining 72 firms. 48 companies responded to the survey (59% response rate). Respondents account for approximately 70% of total industry volume. A copy of the questionnaire is available from the authors upon request.

4. Methodology and Measures

Methodology

Two different methods are used to test the hypotheses. For Hypothesis 1, we use ANOVA to compare the mean level of variety across different structural options while controlling for several significant covariates. To test Hypothesis 2, we use ordinary least squares regression.

Figure 2 Firms Using a Particular Location/Scale Configuration



Variables for Hypothesis 1

Location. A firm is classified as distant from the target market if over 50% of production for a given process (i.e., frame fabrication, frame painting, and assembly) is located outside North America and local if production for a given process is located within the North America.[7]

Scale Efficient. A firm is classified as being scale efficient if production volume at the production facilities exceeds 600,000 units and classified as scale inefficient otherwise.

The combination of the location and scale-efficient variables results in four structural alternatives. However, as seen in Figure 2, we observe firms populating only two alternatives in our data.

The observed classification is robust to large perturbations in our definition of efficient scale. Our discussions with industry personnel yield two common explanations for the resulting dichotomy. First, the distant/scale-inefficient option is dominated by other strategies. In this cell, a firm suffers both production and market mediation cost penalties. Second, the local/scale-efficient option is difficult for firms to achieve. Scale efficiency occurs at 600,000–800,000 units which is approximately 30%–40% of the

[7] We believe the dichotomous variable is justified because firms report that they do not split production evenly between the U.S. and Asia. On average, 90% of production occurs in one location or the other.

North American market. Historically, the largest firms achieve 20% of the market (Bicycling Magazine Subscriber Study 1995). Firms appear hesitant to partner in order to achieve scale locally and third party attempts to provide such a service have not been successful.[8]

The observed correlation between Asian location and scale-efficient production raises the validity threat which companies source in Asia purely for labor cost reasons rather than for reasons associated with economies of scale. Studies frequently cite labor cost advantages as a motivating factor for locating production in Asia (Park 1994). However, other studies suggest that labor cost differences are often transient or offset by differences in transportation costs, tariffs, and quality of output (Terwiesch et al. 1998, MacCormack et al. 1994, Flaherty 1996, Hansen 1987). Such is the case for the bicycle industry in 1997. Since most Asian bicycle production occurs in Taiwan, we use labor cost differences between Taiwan and the U.S. as an example comparison. Labor content of a bicycle produced in a scale-efficient plant is approximately 2.5 hours regardless of location. Fully burdened labor rates in 1997 are \$18/hr in the U.S. and \$6/hr in Taiwan, resulting in a \$30 labor cost differential (*New York Times Almanac* 1999). Transportation from Taiwan to the U.S. is approximately \$6 per bicycle and tariffs on fully assembled bicycles hovered around 11% in 1997 (Wiebe 1998). A bicycle with a retail price of \$500 will have \$225 of materials and plant overhead and a tariff of \$26 (labor + materials × tariff, \$240 × 0.11 = \$26). Thus, the labor cost differential of \$30 is offset by tariffs and transportation (\$32). However, moderate labor cost advantages exist for firms sourcing in China. We address this issue in §5.

We note that 22 of the firms choosing the scale-efficient location also outsource frame production, while 19 of the firms choosing the scale-inefficient location produce frames in-house. These results suggest, in our case, the outsourcing decision exacerbates the tradeoff between production and market mediation costs.

[8] At the time of the study, we noted renewed attempts of third party frame providers to locate plants in North America.

Variety: Materials, Geometry/Size, Components, and Colors. Materials variety is measured by the number of basic materials in a product line. Basic materials include steel, aluminum, titanium, and carbon fiber. Geometry/size variety is measured by the number of different geometries in a product line multiplied by the average number of sizes per geometry. We compute frame geometries as a function of three variables: the type of bicycle (road, mountain, bmx, tandem), whether or not the bicycle has rear suspension, and differences in the frame angles/tube length. Bicycles sharing the same value of each of these characteristics were coded as having the same frame. Color and component variety are measured on a per model and per frame basis rather than on an aggregate basis. We use a per model basis because, in general, once a frame is constructed, colors and components may be shared across any frame. This measurement allows us to more accurately depict the variety offered by a given supply chain. We represent color variety by the average number of colors per model. Because of the high number of components used on a bicycle, we use the number of derailleurs as a proxy for component variety per model.

Unit Sales Volume. Because higher volume has been associated with higher levels of variety (Kekre and Srinivasan 1990), we estimate mean differences in variety while controlling for unit sales volume. Volume is measured using the number of units produced. Firms were asked to indicate a range within which their unit volume fell. The ranges are as follows: below 1,000 units, 1,000–5,000 units, 5,001–20,000 units, 20,001–50,000 units, 50,001–100,000 units, 100,001–200,000 units, and over 200,000 units. The average value of each range is the measure of unit volume.

Variables for Hypothesis 2

Performance Measures. We use two financial measures—return on assets and return on sales—to examine the hypothesis that firm performance is associated with matching variety and location. Both measures capture the cost and revenue benefits associated with matching variety and supply chain structure. Coherent firms will have higher profits

Figure 3 Classifying Variety and Location Decisions as Matched or Mismatched

Materials

	Scale Efficient/Distant	Scale Inefficient/Local
High Materials Variety	Match 20	4
Low Materials Variety	6	Match 13

Geometry/size

	Scale Efficient/Distant	Scale Inefficient/Local
High Geometry/size Variety	8	Match 12
Low Geometry/size Variety	Match 15	8

Color[9]

	Scale Efficient/Distant	Scale Inefficient/Local
High Color Variety	8	Match 15
Low Color Variety	Match 12	8

Components

	Scale Efficient/Distant	Scale Inefficient/Local
High Components Variety	2	Match 20
Low Components Variety	Match 15	6

due to revenue benefits of fewer lost sales, coupled with cost benefits of lower excess inventory costs and lower production costs. These effects all manifest themselves in return on sales and return on assets. Our variables for return on sales and return on assets are perceived performance measures, obtained by asking presidents, vice presidents, or marketing managers of firms to rate their overall performance with respect to industry competition on a 1–7 scale. We use perceived measures because public financial data is not available for many firms in the industry and we found firms more willing to provide perceived financial performance data than actual financial data. However, we were able to collect actual quantitative financial performance for 30 of the 74 firms. Correlation between perceived measures and actual measures for firms providing both sets of data are 0.63, and 0.59 for return on assets and return on sales respectively ($n = 29$). All correlations are significant at the $p < 0.01$ level. While the primary results reported in this paper use perceived measures, we also provide a comparison of results using actual performance measures in §5.

Variety-Supply Chain Match. We code matching of variety and location decisions by placing firms into a four-quadrant matrix for each product attribute based on supply chain structure (scale-efficient/distant vs. scale-inefficient/local) and variety (High vs. Low). A firm is classified in the high variety category if its level of variety with respect to a particular attribute exceeds the sample median. Our theory combined with the supply chain structure of our sample, suggests matches in two quadrants of each matrix. For production-dominant variety (materials), a firm matches by offering high variety from a scale-efficient/distant plant or by offering low variety from a scale-inefficient/local plant. For mediation-dominant variety (geometry/size, components, colors), a firm matches variety by offering high variety from a scale-inefficient/local plant or by offering low variety from a scale-efficient/distant plant. Figure 3 shows the number of firms matching location decisions and variety decisions by attribute. The data indicate that for the majority of product attributes, firms tend to match supply chain structure to product variety in a manner consistent with our theory. We define the measure

MATCH = *materials match* + *geometry/size match* + *colors match* + *components match*, where an attribute match = 1 if the firm matches the attribute to the supply chain structure according to our theory and 0 otherwise. We expect firms matching variety and

[9] Discussions with industry experts revealed a common belief among consumers that painted titanium frames are not desirable. Thus, most titanium companies locating in the U.S. offer only one color. We classify these firms as matching color and location. Results in §5 are robust to this classification.

structure decisions for all four attributes to outperform those that match fewer. To test the robustness of the median cutoff, we used two alternative cutoffs to formulate the MATCH measure. First, the mean was used as a cutoff. Second, the variety measures were divided into quartiles with firms located in the highest and lowest quartiles being matched to the appropriate location. Results of tests using these measures are consistent with those reported in §5. In the results section, we also report that the results are robust to different weightings of the variables that make up MATCH.

Product Mix. During 1997, market demand shifted toward BMX bicycles (Bicycle Industry and Retailer News 1999). We expect firms capitalizing on this trend to garner higher revenues than those failing to recognize the trend. BMX bicycles are also less complex and cost less than road or mountain bicycles. Because of the revenue and cost advantages of selling BMX bicycles, we expect the performance of firms to be positively associated with the percentage of total sales attributed to BMX bicycles. Given these constructs, the equation estimated to test Hypothesis 2 is as follows:

$Return\ on\ Assets/Return\ on\ Sales = \alpha_0 + \alpha_1 MATCH + \alpha_2 UnitVolume + \alpha_3 \%BMX + \varepsilon$, where α_j are regression coefficients and ε is an error term.

Table 2 shows descriptive statistics and the Pearson correlation matrix for the variables used in models testing Hypotheses 1 and 2. We note that the significant correlations match and return on assets provides preliminary support for Hypothesis 2.

5. Results

Hypothesis 1

Table 3 shows the results of mean variety comparisons between the two resulting supply chain configurations. F statistics for the models controlling for production volume are significant in all cases. P-values for the difference in marginal mean variety values are less than 0.03 in all cases except the basic materials case. The marginal result in the basic materials case ($p < 0.11$) is due in part to collinearity between basic materials and unit volume. Results of a model without volume produce p-values less than 0.03. Two threats to the validity of the results merit discussion at this point: labor cost savings in China and flexible production technology.

Labor Cost Savings in China. While we find little difference in unit variable costs per bicycle between the U.S. and Taiwan if transportation costs and tariffs are considered, moderate unit cost savings are available by sourcing in China. The threat to our hypotheses is that the location differences are associated with cheap labor rather than economies of scale. Seven companies in the sample source a portion of their product line in China. To control for the potential effect of low labor rates in China, we reestimated the models in

Table 2 Descriptive Statistics and Pearson Correlation Matrix

Variables	Descriptive Statistics					Pearson Correlation Matrix				
Hypothesis 1:	*N*	Mean	Min	Max	Std Dev	1	2	3	4	5
Basic materials	47	1.91	1	4	0.95	1				
Geometry/Size	46	44.46	4	160	39.65	0.37***	1			
Colors	47	3.94	1	10	3.48	0.06	0.36**	1		
Components	45	2.87	0.22	10	2.40	−0.18	0.21	0.61***	1	
Unit sales volume	48	42396	500	300000	87303	0.29**	0.14	−0.31**	−0.47***	1
Hypothesis 2:						1	2	3	4	5
Return on Assets	43	4.23	1	7	1.47	1				
Return on Sales	44	3.95	1	7	1.62	0.66***	1			
MATCH	48	2.93	1	4	0.86	0.31**	0.22	1		
Unit sales volume	48	42396	500	300000	87303	0.07	0.12	−0.12	1	
% BMX	48	8.37	0	100	19.46	−0.02	0.19	−0.09	0.13	1

Note. ***, **, * correlations significant at $p < 0.01, 0.05, 0.10$ levels, respectively.

Table 3 Mean Variety Differences Between Supply Chains

	Scale Inefficient/ Local	Scale Efficient/ Distant	*P* Value for Difference in Mean	Model *F* Statistic
Basic Materials	1.70	2.15	0.11	3.51**
Geometry/Size	57.93	30.99	0.03	3.09*
Colors	5.73	1.88	0.01	12.05***
Components	3.68	1.00	0.01	15.5***

Note. ***, **, * significant at $p < 0.01, 0.05, 0.10$, respectively.

Table 3 excluding firms locating production in China, and found results consistent with results shown in Table 3.

Flexible Production Technology. Flexible production technology mitigates the scale costs associated with product variety. The threat of flexible production technology to Hypothesis 1 is that the production-dominant attribute—materials—may switch to mediation-dominant depending on the choice of production technology. Ulrich et al. (1997) report that firms face one major flexible technology choice in frame construction which facilitates geometry/size variety rather than materials. Since geometry/size variety is already mediation-dominant, flexible production technology poses no threat to the reported results.

Hypothesis 2

Columns I and V in Table 4 present results of base case tests of Hypothesis 2. *F* statistics for models of return on assets and return on sales are significant and adjusted R^2 range from 0.11 to 0.19 for return on assets and return on sales respectively. White's (1980) test indicated homoskedastic residuals. Examination of studentized residuals reveal several observations with values greater than two. Results are reported without these observations as suggested by Myers (1990). Examination of variance inflation factors indicate no problems with multicollinearity. We find support for Hypothesis 2 as the coefficient for MATCH is positive and significant in model results shown in Columns I and V. The variable %BMX is positive and significant in Column V.

Alternative Hypotheses and Specifications for Hypothesis 2

Is One Matching Strategy Better Than Another? The MATCH measure assumes that matching variety and structure with respect to each attribute is equally important to profit. In fact, the results could be driven by decisions about one attribute only. The MATCH variable assumes equal weight for matching variety strategy with respect to each attribute, and so we tested the robustness of this weighting scheme. First, we assigned sets of random weights to each attribute match before summing to obtain the MATCH measure. Second, we examined the influence of each individual match on the construct by assigning zero weight to a single match and equal weight to the remaining matches then recalculating the MATCH measures and reestimating the models after each MATCH recalculation. Results using these measures were consistent with those reported in Table 4. In a final test for robustness, we estimated performance models including match for each attribute as independent variables (Table 4, Columns II and VI). In general, we find that coefficients indicate that performance increases with the individual match. The coefficients for the materials and geometry/size matches are positive and significant. However, *F* statistics testing for differences across all individual match coefficients yield no significant results. Pair-wise comparisons of coefficients indicate the only significant differences exist between the materials match and component match and between the geometry/size match and component match. Thus, we find little evidence that a single matching strategy is better than another.

Is More Variety Better? Several streams of literature including variety postponement (Lee 1996, Lee and Tang 1997), mass customization (Pine 1990), and time-based competition (Stalk 1990) suggest that firms aligning supply chains to offer high variety will outperform those choosing not to offer variety. If true,

Table 4 Association Between Performance and Variety/Supply Chain Match

Panel A: Median Method

	Return on Assets ($N = 37$)				Return on Sales ($N = 40$)			
	I	II	III	IV	V	VI	VII	VIII
Intercept	1.97***	2.28***	1.56*		1.90**	1.12*	2.12*	3.51***
	[2.99]	[3.02]	[1.89]		[2.24]	[1.71]	[1.97]	[4.02]
MATCH	0.63***	—	0.56**		0.57**		0.58**	
	[3.38]		[2.56]		[2.18]		[2.04]	
Materials Match		1.03*				1.72***		
		[1.83]				[2.95]		
Geometry/size Match		1.31***				1.35**		
		[2.81]				[2.46]		
Colors Match		0.33				0.12		
		[0.69]				[0.21]		
Components Match		0.15				−0.02		
		[0.27]				[−0.03]		
Unit volume	−0.0001	0.0001	0.0001	0.0001	−0.0001	0.0001	0.0001	0.0001
	[−0.13]	[0.38]	[0.53]	[0.53]	[−0.03]	[1.16]	[0.20]	[0.21]
% BMX	0.01	−0.002	0.01	0.01	0.02*	0.01	0.02	0.02
	[0.79]	[−0.24]	[1.11]	[1.20]	[1.99]	[1.21]	[1.39]	[1.34]
Basic materials			−0.08	−0.10			−0.09	−0.09
			[−0.31]	[−0.36]			[−0.27]	[−0.28]
Geometry/Size			−0.01	−0.01			−0.01	−0.01
			[−0.77]	[−0.40]			[−1.14]	[−1.04]
Colors			0.07	0.09			0.09	0.10
			[0.95]	[1.11]			[0.88]	[1.00]
Components			0.18	0.29*			−0.04	−0.03
			[1.26]	[2.00]			[−0.28]	[−0.17]
Supply Chain Structure			0.51	0.78			0.18	0.36
			[0.79]	[1.13]			[0.23]	[0.42]
F statistic	3.88***	2.03*	1.92*	1.05	2.58*	2.68**	1.16	0.66
Adjusted R^2	0.19	.14	0.17	0.01	0.11	0.19	0.03	−0.06

Note. t statistics in brackets.

firms appropriately matching high variety with structure will outperform those matching low variety and structure. We test the basic notion that more variety is best in two ways. First, variety and structure measures are included in Columns III, IV, VII, and VIII of Table 4 to test the direct effects of variety and structure. We find no significant effects, with the exception of components in Column IV. The results suggest little direct association between variety and higher profits, providing further evidence for the hypothesis that higher performance is achieved through proper alignment of supply chain structure and variety, rather than through variety or supply chain structure by themselves.

Second, we divided the MATCH variable into two variables—LOW VARIETY MATCH and HIGH VARIETY MATCH—then reestimated the performance models for return on assets and return on sales. Results of these tests are shown in Table 5. *F* statistics testing the hypothesis that $\beta_{\text{HIGH-VARIETY-MATCH}} = \beta_{\text{LOW-VARIETY-MATCH}}$ indicate no significant differences between coefficients. Thus, we cannot conclude that high-variety matching strategies yield higher performance than low-variety matching strategies.

Comparison of Perceived and Actual Performance Measures: To test the robustness of our results to the use of perceived performance measures vs. actual performance measures, we estimate models shown in Table 4 using the subset of firms, which provided

Table 5 Association Between Performance and HIGH/LOW VARIETY MATCH

	Return on Assets	Return on Sales
Intercept	2.43***	1.49*
	[3.29]	[1.76]
HIGH VARIETY MATCH	0.60**	0.61**
	[2.55]	[2.81]
LOW VARIETY MATCH	0.64**	0.97***
	[2.55]	[2.29]
Unit Sales Volume	−0.000001	0.000002
	[−0.56]	[0.63]
% BMX	0.002	0.01
	[0.21]	[1.25]
F statistic	1.94	2.77**
Adjusted R^2	0.09	0.15
N	41	42
$F: \beta_{\text{HIGH-VARIETY-MATCH}} = \beta_{\text{LOW-VARIETY-MATCH}}$	0.02	1.59

Note. ***, **, * significant at $p < 0.01$, 0.05, and 0.10 levels, respectively—two tailed tests; *t* statistics in brackets.

actual performance measures. We also estimated models using a combined perceived and actual performance measure. The combined measure was calculated by using the actual performance measure where provided and a predicted measure of performance where firms did not provide actual performance measures.[10] For return on assets, the total match measure is positive and significant. However, the individual match measures lose significance while retaining their positive signs. We noted that *F* statistics for both models were not significant, suggesting the smaller sample size is limiting the power of the tests. For return on sales, the sign on the total match measure is positive, but the *t* statistic is not significant. However in individual match models, the coefficient on the geometry/size match is positive and significant. As in the case of return on assets, we noted that *F* statistics for both models were not significant. The results reported above were consistent across actual and combined measures of performance.

[10] The predicted measure was calculated by regressing perceived measures on actual measures. The results were as follows: actual ROA $= 1.1085 + 0.7793$ (perceived ROA) adjusted $R^2 = 0.37$, actual ROS $= 2.3022 + 0.4733$ (perceived ROS) adjusted $R^2 = 0.33$.

6. Limitations and Conclusions

The basic findings of this study support the hypothesis that product variety is related to supply chain structure through its effect on production costs and market mediation costs. Specifically, we find that production-dominant variety is positively associated with scale-efficient/distant production while market-mediation dominant variety is positively associated with scale-inefficient/local production. We also find evidence that firm performance is positively associated with correctly matching supply chain strategies to product variety strategy.

At this point, several issues merit discussion. First, a concern with any single industry study is the degree to which one may generalize the findings. The basic results of the empirical analysis are driven by the specific economics of the bicycle industry, but we believe several aspects of the study findings are germane to other industrial settings. The cost tradeoffs between production costs and market mediation costs are present anytime a firm chooses to locate production outside its target market. Consumer electronics, and notebook computers are examples of industries where these tradeoffs exist. However, one limitation of our data is that there are no firms in this segment of the industry with sufficient scale to pursue the dominant strategy of centralizing within the home market and offering both production and mediation-dominant variety. Therefore, we cannot test whether firms pursuing this strategy outperform the firms in our study.

Second, we emphasize that our hypotheses only test for an association between supply chain structure and variety. Establishing causality between these two constructs is a matter for future research. As preliminary evidence, our examination of two leading bicycle firms over time suggests an initial choice of supply chain directly impacts the type and amount of variety offered over time. Using historical data from 1985–1997, we examined the variety offered by two firms: Cannondale and Specialized. Since its founding, Cannondale has located production in the United States while Specialized has located production in Asia. Over this time period, Cannondale offered bicycles of only one material, aluminum, while Specialized began offering steel bicycles, but now offers steel, aluminum, and composite frames. On the other hand, Cannondale has developed flexible production technology allowing it to offer a wide variety of frame geometries, while Specialized offers very few geometries (Ulrich et al. 1995). These observations suggest that a firm's choice of variety type may be affected and driven by the capabilities of the existing supply chain. Such behavior is logical, given that product line decisions are typically made frequently relative to supply chain decisions.

Third, any conclusions about outsourcing drawn from our study must be taken in the context of the industry. We theorized that outsourcing either mitigates or exacerbates the relation between variety, market-mediation, and production costs. Firms have incentive to obtain scale to provide production-dominant variety. In our specific case, scale-efficient suppliers are found outside the target market exacerbating the cost tradeoffs. This may not be true in other industries.

Fourth, contradicting theory suggests that plants with scale can mitigate market mediation costs through inventory pooling. We listed several criteria necessary for this effect to be present including: (1) product characteristics are not specific to each regional market, (2) firms hold inventory at the scale efficient location, and (3) savings from pooled inventory outweigh the potential lost sales because of longer response time. We observed violations of the criteria in our specific industry context. However, if present, these conditions would allow firms to mitigate market-mediation costs in a scale-efficient location, suggesting that firms might manage these cost tradeoffs by globalizing product characteristics and holding central inventories rather than changing the structure of the supply chain.

Finally, we found no evidence to suggest that offering more variety through strategies of mass customization or variety postponement results in higher firm performance. However, we are hesitant to dismiss the promise of such strategies. Interviews with industry personnel suggest that the effectiveness of high variety strategies lies in the ability of the firm to correctly reach a target market. In bicycles, firms face an increasing challenge of how to communicate and educate consumers about the available choices. This suggests that the ultimate success of high-variety strategies may rest not only on a supply chain's ability to physically deliver variety, but also on the ability to communicate and present options to consumers.

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