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Linking Product Variety to Order-Fulfillment Strategies

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Providing a variety of attributes in products is an important way of attracting customers, but it often increases complexity and managerial cost. We drew on two data sets collected in the automotive sector to explore the link between external variety (the variety offered the customer) and internal variety (the variety involved in creating the product). We found that these two dimensions can be independent of each other. External variety is problematic for firms producing to forecast, and handling internal variety is challenging for firms building products to order. The effectiveness of strategies to mitigate variety's negative effects, such as modularity, mutability, late configuration, and option bundling, depends on the order-fulfillment strategy the firm follows.

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The automobile industry has come a long way since Henry Ford ruled that "they can have any color as long as it is black." He wanted to root out variability in the production process and enhance efficiency (black paint dried faster than other colors). The automobile industry has since incorporated product variety into Ford's mass-production approach. Today buyers of mainstream vehicles choose from a wide range of body styles, engines, colors, trims, and options. From a marketing perspective, firms offer product variety on the premise that the attributes of goods determine their value and that variety is a key driver of utility. Their assumption is that customers derive utility by choosing among attributes or characteristics of a product (Lancaster 1990, Rosen 1974).

Demand-side pressures, such as preempting competitors' offerings and differentiation strategies, drive firms to vary their products. If they make the product-choice strategy work, "each customer finds exactly the option he or she desires" (Kahn 1998, p. 46). However, those managing variety from the demand angle and those managing variety from the supply side conflict somewhat. While variety helps marketing units blanket a product space and entice new customers, developing and producing that variety is challenging. Product variety hence defines a key interface between marketing and operations, customers and factories. Reducing or delaying variety decreases manufacturing and logistics costs but may also affect design costs and reduce revenue by limiting the offerings in the marketplace.

Although researchers have examined ways to determine optimum variety levels (Ho and Tang 1998), they have reached no definitive conclusions on product variety's impact on manufacturing operations (MacDuffie et al. 1996). The "solutions" proposed to mitigate any negative impact variety may have on manufacturing range from product-design approaches, such as broader use of common product platforms and modularity (Baldwin and Clark 1997, Meyer and Lehnerd 1997, Sanchez and Mahoney 1996, Starr 1965), to process innovations, such as late configuration and postponement (Pagh and Cooper 1998). The success of any strategy intended to mitigate the impact of product variety depends on the operation of the value chain and therefore cannot be discussed or evaluated in isolation.

In the auto industry, most volume car manufacturers still build vehicles to forecast, stockpiling them at dealers and distribution centers in an effort to give customers choices. While some manufacturers are beginning to build vehicles to specific end-customer orders, the transition is a difficult one and product variety is particularly challenging (Holweg and Pil 2001, 2004). Automobiles are very complex products, and we felt the auto sector was therefore an especially useful setting to examine how variety is best managed in relation to order fulfillment.

We relied on two sources of data to evaluate different strategies for managing product variety: (1) vehicle-manufacturer information on the product variety the top 10 manufacturers offered in the European market in 2002 for their two best-selling models and the variety they offered customers in the decade leading up to that point, and (2) the results of a global survey of automotive assembly factories we performed under the auspices of MIT's International Motor Vehicle Program. We based our survey on earlier efforts to assess variety in the auto sector (MacDuffie et al. 1996). We designed it for distribution to specialists within assembly facilities. We relied on senior managers (for example, head industrial engineers or plant managers) to coordinate the surveys. Before contacting individual plants, we obtained agreement from corporate headquarters and industry associations. We sent out 95 surveys, and the vehicle assembly plants returned 70, representing 17 vehicle manufacturers around the world, which included nine of the top 10 vehicle manufacturers. Most of the factories responding were quite large, producing core company products, and an average of 820 vehicles per day. The plants were located primarily in North America, Western Europe, Japan, Korea, South Africa, and Australia. (We will make the survey, as well as precise plant distribution, available on request.)

The Dimensions of Product Variety

Much of the research examining the implications of variety for the link between production and distribution concerns product variety in isolated segments of the value chain. Researchers have defined variety inconsistently or inadequately and produced little conclusive empirical evidence (Southey and George 1998). Prior research shows that we must consider two types of variety to understand its role in the value chain: external and internal product variety.

External Variety

Fisher and Ittner (1999) estimate the choice offered to the customer, or external variety, by multiplying all possible features offered (for example, 4 body styles × 12 power-train combinations × 10 exterior colors × 3 interior colors × 15 options). However, such estimates are not always accurate. For every main model, one must calculate the total variations separately because the manufacturer may offer different options for each derivative. For example, it may offer an optional roof rail only on estate cars, no sunroof on convertibles, and so forth. As a result, multiplying body styles by power trains, by paint and trim combinations, and by number of option choices does not yield an accurate count of the number of possible variations available to the customer. We examined the actual variety the key European (VW, Renault, PSA, Fiat), American (Ford, GM), and Japanese (Toyota, Nissan) producers offered for their two best-selling products or models in Europe in 2002, as well as the actual variety two luxury producers (BMW, Mercedes) offered for their two best-selling products. We based our calculations on company material, to accurately measure only the variations and combinations customers can actually order (Table 1).

The manufacturers offer all their vehicles in many body styles, power trains, and combinations of interior trim and exterior paint. With the exception of VW, Mercedes, and BMW, they do not differ greatly in the range of engines or paint-trim combinations they offer. However, they differ dramatically in the total actual product variations they offer. This ranges

Model	Bodies	Power trains	Paint-and-trim combinations	Factory-fitted options	Total number of variations	European sales in 2002 [units]
Peugeot 206	3	8	70	5	1,739	596,531
VW Golf	3	16	221	26	1,999,813,504	595,465
Ford Focus	4	11	64	19	366,901,933	523,356
Renault Clio	2	10	57	9	81,588	502,497
Peugeot 307	4	8	70	9	41,590	441,468
GM Astra	4	11	83	14	27,088,176	440,567
GM Corsa	2	9	77	17	36,690,436	420,296
Fiat Punto	2	5	51	8	39,364	416,843
VW Polo	2	9	195	27	52,612,300,800	357,539
BMW 3-Series	3	18	280	45	64,081,043,660,000,000	350,723
Ford Fiesta	2	5	57	13	1,190,784	294,360
Renault Megane	2	6	52	14	3,451,968	261,383
Mercedes C-Class	2	16	312	59	1,131,454,740,000,000,000,000	254,836
Toyota Yaris	2	6	30	8	34,320	194,256
Fiat Stilo	3	7	93	25	10,854,698,500	173,453
Mercedes E-Class	2	15	285	70	3,347,807,348,000,000,000,000,000	157,584
Toyota Corolla	4	5	24	6	162,752	139,837
Nissan Micra	2	6	30	4	676	106,428
Mini (BMW)	1	5	418	44	50,977,207,350,000,000	105,617
Nissan Almera	3	5	30	5	3,036	87,474

Table 1: In 2002, firms in the European automotive sector differed dramatically in the level of variety they offered customers, yet variety bore little relation to sales.

from several hundred to almost astronomically high numbers, exceeding what the firms can possibly sell over the vehicles' product life cycles. Clearly, firms differ drastically in the variety they think they need to offer.

The main driver for this external variety is the number of options automobile firms offer to their customers (correlation = 0.60). While we expected that sales volume would play a role in determining how much product variety a firm offered, we found no significant correlation between sales and total variety offered (correlation = −0.23).

Internal Variety

As the firm translates the external variety it offers to the customer into requirements for the manufacturing process and the value chain, it creates internal variety. Following MacDuffie et al. (1996), we measured internal variety in terms of the complexity of three levels of the product structure: (1) the fundamental internal variety, which for automobiles includes the models and body styles offered for a vehicle, (2) the intermediate internal variety that provides further customer differentiation, such as power trains, the number of wire harnesses connecting all electrical elements in the vehicle, power trains, and vehicle colors, and (3) peripheral internal variety, or the overall number of components installed per product, as well as the variety of these components.

In the automotive sector, the body (weld) part of the factory defines the number of openings (doors, hatch), the engine compartment, and the main floor. It produces the *body in white*, the welded steel shell of the vehicle. The shells are the basic structural and support frameworks upon which the factories generally build cars, and thus they reflect fundamental internal variety. A body in white consists of an engine compartment (the metal cavity under the vehicle hood that contains the engine, radiator, battery, and so forth), the main floor pan or underbody of the vehicle, the body sides, and the roof. The body in white reflects the platform, model, and body style (two-door, four-door, hatchback, or convertible) of the particular vehicle. It may be customized to handle specific options, for example engine type or the presence of air conditioning. For different engines, for example, the factory might weld different engine compartments with brackets and supports that are engine specific.

To determine how external and internal dimensions of variety relate to each other, we compared the number of body-in-white variants the factory produced to the number of engine, transmission, and door characteristics it offered. If internal variety and external variety are related, we would expect that the body-side variations would be linked to the number of door variants offered. Likewise, we would expect that the number of engine compartments would be related to the number of engines offered and that the number of underbody variations would be related to the number of transmissions offered.

Plants that have many variations of one aspect of the body in white are likely to have many variations of other aspects of the body in white; for example, body-side variations will be comparable to underbody or engine-compartment variations (Table 2). However, the variety in the body in white bears no relation to the external variety. Thus, for example, the number of body sides the plant uses bears no relation to the number of door variants it builds for the car. Some of the variety in doors it offers has nothing to do with the interface between door and body side (for example, interior trim color and speaker choice). Engines are more directly related to their compartments. However, the number of engine-compartment types produced is not correlated with the number of engine variations produced for customers. Some plants fit many engine types into one type of engine compartment, while others require a unique engine-compartment design for each engine type.

We conducted follow-up interviews with assembly-plant management teams at 15 plants. We found that plants that use many body-in-white variants seek to reduce the number of brackets and welds they must

	Median	Door variations	Engine variations	Transmission variations	BIW-Vehicle side variations	BIW-Engine-compartment variations	BIW-Underbody variations
Door variations	19.25	1.00					
Engine variations	8	0.785**	1.00				
Transmission variations	7	0.042	0.235	1.00			
BIW-Vehicle side variations	3	−0.061	−0.096	−0.119	1.00		
BIW-Engine-compartment variations	2	−0.076	−0.058	−0.111	0.778**	1.00	
BIW-Underbody variations	3	−0.069	−0.009	−0.088	0.808**	0.785**	1.00

Table 2: Firms that are high on one dimension of internal variety are generally high on other dimensions of internal variety as well. However, internal variety bears no relation to the external variety offered to customers. Because of outliers, we report medians rather than means. BIW stands for body in white.

** = **Sign at 0.01 level (2-tailed).**

add to the metal body shell. A body in white that accommodates many engine types, for example, must have the brackets and welds to support all potential engine types. Some body-shop managers said they would prefer mutable products (for example, bodies in white that do not need to be customized for each engine, but can accommodate all variants), but the vehicle designs precluded that possibility.

Variety and Order-Fulfillment Strategies—Linking External to Internal Variety

According to Mather's (1988) order-fulfillment framework, firms use two generic strategies to satisfy customers' demand for variety: (1) build to forecast and (2) build to customer order. In the build-to-forecast approach, the production process is driven by an aggregated sales forecast. In the build-to-order approach, the individual customer order initiates the production process.

When the production process is driven by an aggregated sales forecast, the firm can achieve high and stable capacity utilization and economies of scale by batching orders (Raturi et al. 1990). Raw-material producers, such as steel mills, often use forecasts to obtain the stable and sophisticated production schedules their equipment requires. On the downside, forecast-driven systems rely on costly inventories of finished goods, and forecast errors may cause them to hold obsolete inventory or to fail to fill customers' orders promptly.

In systems driven by customer orders, manufacturers hold little finished inventory because they customize all products to meet individual orders. On the downside, order-driven production responds to swings in demand and thus varies in capacity utilization and may suffer from long order lead times because the system holds no products in stock (Holweg and Pil 2001).

Researchers have described a range of hybrid order-fulfillment strategies, generally varying on how far the order travels up the value chain. Mather (1988) distinguishes make-to-stock, assemble-to-order, make-to-order, and engineer-to-order fulfillment strategies. For example, in the assemble-to-order scenario, the plant produces components to meet a forecast and assembles them into final products to fill customer orders. With this strategy, the value chain has both forecast and order-driven parts separated by a decoupling point where the plant assembles the forecast-driven components into customer-ordered products.

While the placement of the decoupling point has drastic implications for the system's performance, the product's initial consideration from a variety perspective is whether it bases its final production (and customizing) process on a potentially inaccurate forecast or on individual orders.

The extent of external variety offered customers indicates the impact variety will have on the value chain. Some argue that external variety may increase both sales and manufacturing cost (Lancaster 1990). Great external variety has serious drawbacks when manufacturers build products to forecast and sell them from stock. The more product variations they offer, the more difficult it is to find the product an individual requests among those in stock. Manufacturers building cars to forecast hence face a serious dilemma: they must either reduce choice to minimize stock levels or risk compromising their ability to supply the exact products their customers want. New-vehicle-buyer research in the UK shows that almost 22 percent of customers did not get the exact vehicle they requested; 46 percent of these customers received financial recompense for compromising (Elias 2001). The practice of selling from stock prevails for approximately 50 percent of vehicle sales in Europe and for 95 percent of recent vehicle sales in the US (Holweg and Pil 2001, Williams 1999).

The total number of product permutations provides only a partial picture of the impact of product variety on the value chain. The volume per product, or per product derivative in this case, determines its impact on the production system according to Christopher and Towill (2001). They argue that frequently ordered and stable-volume products require a different strategy from infrequently ordered and low-volume products. Child et al. (1991) suggest that the latter—the tail three percent of the sales variations—accounts for 30 percent of the overall product cost and should be eliminated completely.

We examined proprietary sales data for three of the top 10 European vehicle producers in 2000; we expected to find a standard Pareto relation between the sales and the number of variants offered, whereby 80 percent of the volume would be accounted for by approximately 20 percent of the variants. Instead, we found significant variance, with 80 percent of sales accounted for by two to 14 percent of the variants offered, depending on the car under consideration. The reason is that not one but several Pareto relations underlie the volume distribution. We found substantial relations for various core vehicle characteristics (for example, the 2.0 16 V manual power train and the three-door-hatchback body style), add-on-option combinations (for example, the front fog lamps always bundled with a spoiler kit), and paint-and-trim combinations (green color and beige interior trim). This variation is fundamental to the distribution-center or central-stock concept, whereby a strictly reduced overall variety and a Pareto-like distribution of the demand potentially enables manufacturers to hold the high-volume "runner" variants in a central finished-goods inventory and supply those from stock.

Vehicle manufacturers, such as Peugeot, take this approach in their distribution systems. Peugeot dealers in the UK do not hold any new-vehicle stock, and yet they can obtain any vehicle stocked in the four central locations in the country within 24 hours. Peugeot has drastically limited external variety, and it has designed its system so that 75 percent of the products customers choose are available in the distribution centers. The remainder is available on a build-to-order basis at lead times of several weeks.

By examining external variety, we found that its link to internal variety is not always clear. It is critical, however, to examine the two types of variety in concert to understand the effectiveness of the mitigation strategies researchers have proposed, such as option bundling, late configuration, modularity, and postponement (Baldwin and Clark 1997, Meyer and Lehnerd 1997, Pagh and Cooper 1998, Sanchez and Mahoney 1996). We examined different dimensions of product variety and strategies for mitigating the negative impact of variety on the value chain. We did not examine mass customization directly (Pine 1993), because it is an umbrella concept made up of a continuum of strategies. Gilmore and Pine (1997), for example, include modularity and late configuration as two strategies to attain mass customization.

Mutable Support Structures

The term *mutable support structures* refers to any components designed to support multiple product configurations, such as standardized engine-mounting brackets, wiring harnesses, or bodies in white. Plants that have support structures that are not mutable (and as a result need many different types to support the multiple product configurations) face a challenge in predictably building a range of product configurations. For example, as a factory produces a nonmutable body in white, it assigns it to a specific product order for, say, a green hatchback with 2.2 liter engine, manual transmission, and air conditioning (either based on forecasted projections or what will sell or specific customer orders). However, our assembly-plant-survey data show that, across the 70 assembly plants, the average first-time-OK rate (fraction of products making it through the process that require no corrective repair) in the body shop is 94 percent, and the average first-time-OK rate in the paint shop is 84 percent. While some production managers argued that early assignment of specific bodies to orders put pressure on the plants for continuous improvement, even at the best plants, first-time-OK figures in body and paint shops hover around 98 and 85 percent, respectively. Hence, almost one in five vehicles does not make it through the body and paint shops without corrective repair. If the plants tie customer orders to specific bodies in white, the repairs delay those orders. While a larger number of body-in-white variants increases complexity, it has its greatest effect on systems that build vehicles to order, because customers do not get their cars promptly. In a build-to-forecast setting, delays in producing particular vehicles do not disappoint individual customers.

To build to customer order, it is desirable to permit late order tagging; if one body in white does not make it through the paint process, the plant can substitute another one. For this to work, bodies in white and other support structures need to be *mutable*, that is, the plant can swap one support structure for another without changing the final attributes the customer wants. As a production engineer with a European vehicle manufacturer put it, "With fewer (painted body) varieties, we are able to assign painted bodies to the most urgent customer orders and increase delivery in the (acceptable time) window."

While this may mean a more complex support structure from a design perspective (in the case of bodies in white, the body in white should accommodate all engine variations and options), it greatly simplifies the logistics and manufacturing processes associated with building vehicles to order.

As support structures, wire harnesses can be customized to accommodate specific options, such as electric windows or heated mirrors, or can be mutable to accept many options. Most of the assembly plants in our sample manage at least 19 wire harnesses, and most have many more. They are usually designed to accept peripheral variety (in the form of options in discrete combinations). Usually suppliers manufacture and deliver them to the manufacturer just in time for specific vehicles. However, because the harnesses are intended to accept specific combinations of options, they prevent order swapping. A problem with a harness or the vehicle it is intended for will delay the customer order. At least one manufacturer created mutable wire harnesses: "... we have only one wire harness—there's no chance of getting the wrong harness, and the customer can have any options he wants up to the last minute" in the manufacturing process (factory manager of a European auto vehicle manufacturer).

Because the wire harnesses are not option specific, the manufacturer can add any combination of options to the vehicle, and if a harness malfunctions, it can easily substitute another one. With a custom harness, it would have to pull the particular vehicle until it could get a new one. From a design viewpoint, a mutable wire harness is more complex and requires much more sophisticated software than a custom harness, but the reduced variety enables the firm to amend orders late in the process and swap options.

A mutable support structure thus facilitates building to customer order by reducing internal variety and enabling flexibility in responding to orders.

Mutability improves the logistics of building vehicles to forecast, but because no end customer is waiting for a specific product to emerge from the pipeline, the flexibility offered by mutability provides little value. Eliminating mutability often saves money via leaner and less complex designs (for example, no need for all potential brackets to support all engine types in the body in white), and this may be worth it if the delays resulting from in-process rectification do not affect the relationship with the end customer.

Mutable support structures may cost more than customized ones in design and materials, but they reduce internal variety and enable flexible manufacturing. The firm may be able to reduce its inventory of finished vehicles by cutting order-to-delivery lead times for vehicles built to order. In contrast, for products built to forecast, adding any external variety greatly increases the complexity of logistics, distribution, and inventory postproduction, and mutable support structures do little to reduce this increase. However, mutable support structures that facilitate the application of key components across multiple products can increase external variety without damaging economies of scale in both build-to-order and build-to-forecast systems. When the product on which the vehicle is designed and built is mutable, the firm can achieve economies of scope and scale (Meyer and Lehnerd 1997). Between 1990 and 2002, the sales volume per body style for the eight vehicle manufacturers we analyzed in Europe fell by 47 percent. As a countermeasure, the manufacturers have used product platforms as a key strategy to obtain the overall sales volumes they need to attain the economies of scale required to recover development and tooling costs (Table 3). They have steadily increased the number of body types per platform, thus increasing the average production volume per platform and offsetting reductions in volumes per body type and model. We expect these trends to continue. VW forecasts that its new platform PQ35, for example, which underlies the Audi A3 and the fifth generation of the Golf, will exceed annual production volumes of two million vehicles by 2007. Other companies are taking similar measures. GM is cutting its passenger-car platforms from 13 in 2000 to seven in 2005, and Nissan and Renault are moving to 10 shared platforms (Winter and Zoia 2001). Nissan alone had 24 platforms in 1999 (Ghosn 1999).

Modularity

The trend in many industries is to reduce complexity by modularizing technologies and the associated organizational capabilities and to increase the outsourcing of productive activities. Modular designs and associated production approaches are now widely used in manufacturing (Sako and Warburton 1999), software (Cusumano 1991), and computer hardware (Baldwin and Clark 1997), and in many service industries (Baldwin and Clark 1997, Sanchez and Mahoney 1996). The idea behind modular architectures is to create a one-to-one mapping between a set of physically proximate components, or subassemblies, and particular functions. Each module drives the performance of one function, and each function is affected by only one module (Ulrich 1995). One-to-one mapping (in contrast to functions distributed across multiple components) reduces interdependencies among components that affect specific performance criteria. While modularity has key benefits from a design perspective, it also reduces complexity from a manufacturing perspective.

In the automobile industry, modules are not as cleanly linked to specific functions as prescribed in

	1990	1995	1996	1997	1998	1999	2000	2001	2002	Change 1990–2002 (%)
No. of platforms in use (all Europe)	60	60	57	56	53	49	43	43	46	−23.3
No. of body types offered (all Europe)	88	137	139	148	157	159	167	175	179	+103.4
Av. No. of body types per platform	1.5	2.3	2.4	2.6	3.0	3.2	3.8	4.0	3.9	+160.0
Av. production volume by platform (in ’000s)	190	166	178	191	218	244	285	283	269	+41.6
Av. production volume by body type (in ’000s)	129	73	73	72	74	75	73	70	69	−46.5

Table 3: In Europe the number of passenger-car body types is increasing dramatically over time. As a result, production volumes per body type are decreasing. To offset this reduction in volume, firms are increasing the number of body variations they produce on each platform. Data sources: Automotive News Europe (2002, 2003), J. D. Power–LMC (2002a, b), *Ward's Yearbook* (1991), *World Car Industry Forecast Report* (1996), World Motor Vehicle Data (1998).

the academic literature. With the exception of seats and perhaps door inners (also known as door cassettes or door plugs), most modules are really complex subassemblies the manufacturers insert into their vehicles in the final assembly process. However, the benefits from a manufacturing perspective are retained.

Modules shift complexity off the main assembly line and into subassembly lines or to outside suppliers. Variability in options is less critical in the subassembly lines or contracted operations because they are decoupled from the main line and thus do not affect the broad production process. Furthermore, manufacturers can test subassemblies before inserting them into the main line. Thus modularity can help firms contain the complexity associated with internal product variety. Modularity offers benefits to both forecast- and order-driven value chains by reducing complexity within the assembly process and enabling a flexible assemble-to-order approach.

Option Bundling

Manufacturers commonly bundle or package options to reduce external variety. Rather than offering every option separately, they reduce the choice to predetermined sets of options. With this strategy, they directly address the key driver of external variety, the number of options offered. Option bundling does not affect internal or dynamic variety, although, according to Fisher and Ittner (1999), option bundling can reduce the buffers inside the manufacturing plant.

Automotive manufacturers use option bundling mainly to reduce forecast error and thus the obsolescence risk of stock (Batchelor 2000). Option bundling is an important strategy for managing external variety in a forecast-driven value chain. Firms can greatly simplify their whole distribution system by offering options as coherent bundles rather than offering all possible permutations of options.

Option bundling has no influence on the distribution process for build-to-order products. Once a firm manufactures a product to a customer's order, the challenge is to get it to that customer, and the options offered play no role in doing so. The only benefits from option bundling that we have seen for build-to-order manufacturing derive from reducing manufacturing error, because the plant always installs the options in specific combinations.

In the auto sector, option bundling reduces external variety. Renault relies on option bundling for its Megane Classic while its market equivalent, the Ford Focus Saloon, does not. Both models offer one body style and 17 factory-fitted options. Renault offers five power trains, 10 colors, and four trim levels. It tightly packs the options into 18 power-train, trim combinations, resulting in a total choice of 870 variations out of a total 26,214,400 possible combinations. In contrast, Ford offers eight power trains, 12 colors, and two trim levels. Customers can choose and combine the 17 options in many ways, resulting in a real choice of 5,898,240 variations, out of a total 75,497,472 variations. Renault's option bundling thus results in a much lower level of external variety than Ford offers, increasing the likelihood its customers will find the cars they want in a build-to-forecast environment. Option bundling may also help customers chose from inordinate numbers of choices.

Late Configuration

By using late configuration (or postponement), manufacturers delay customization to bring it closer to the order point. This tactic may take different forms. For example, in the auto sector, MCC's Smart has a gearbox with a software switch to configure the transmission as automatic or semiautomatic. The late configuration can take place during the main production process or afterwards. Honda in Europe configures body kits, alarms, and trim accessories in its distribution centers. Its sales and distribution manager said, "We use the distribution centers not only as stock buffers, but also as value-added operations to configure and prepare vehicles to customer specifications. This takes complexity out of the assembly operations and is more flexible to customer requirements."

Firms use late configuration to remove internal variety from the assembly process, and when distribution centers or dealerships perform the configuration, it reduces the number of (nearly) finished product variants the system must keep on hand to meet a particular level of external variety. However, several vehicle manufacturers indicated to us that late configuration might damage quality when performed on components designed to be assembled in an integral fashion with the remainder of the vehicle. Late configuration hence is most effective in forecast-driven value chains, where firms can use it to position internal variety optimally in the value chain to delay some customization until the point of purchase.

Toward a Systems Perspective of Variety—Managerial Guidance

By investigating the link between internal product variety and external product variety jointly with order-to-delivery strategies, we have tried to understand how firms can best meet the challenges posed by variety. Based on empirical evidence from the automotive industry, we reached two main conclusions:

(1) Internal variety and external variety can be decoupled and managed independently, and

(2) The negative impacts of variety depend on the order-fulfillment strategy. As a result, mechanisms

that reduce variety's impact in a forecast-driven firm may provide minimal benefit to firms that build products to order (and vice versa).

Within forecast-driven systems, external variety affects forecast error and determines the amount of inventory the firm needs to satisfy its customers. In order-driven systems, the level of external product variety is dictated by each customer order. Since the system operates without finished-goods inventory, external variety does not pose the challenges it does in a forecast-driven system. Instead internal variety directly determines manufacturing flexibility. Manufacturers must manage the associated complexity to operate such order-fulfillment systems successfully. They can use mutable support structures to achieve the flexibility they need to fill customers' orders promptly. With build-to-order systems firms must reduce the complexity before customization and at the point of customization.

How a firm effectively mitigates the effects of offering variety depends upon its order-fulfillment strategy. In a make-to-forecast scenario, process flexibility is not critical, and thus internal variety and overall manufacturing flexibility are not important drivers of success. However, the more external variety a manufacturer offers its customers, the more inventory it must hold. In their distribution systems, vehicle manufacturers try to match thousands of permutations of their products to customers. Firms may be tempted to reduce external variety to simplify the process of matching customers with cars. Forecasts are rarely perfect, and as a result, there are risks that some products made will not sell as anticipated. High-variety strategies provide some insurance against that risk (Kahn 1998). In a build-to-order scenario, approaches that mitigate internal variety, particularly internal variety precustomization, are key.

Generalizing from Autos

We synthesized our findings and developed a framework of ways to address the challenges posed by product variety (Table 4). We distinguished between forecast-driven systems and order-driven systems, even though manufacturers may use both strategies in parallel within the same value chain. (For example, suppliers may produce components to order for a vehicle manufacturer and to forecast for the aftermarket of service parts.)

Option bundling and late configuration are most effective in forecast-driven value chains because they facilitate guided choice and mitigate forecast risk. They are of limited value in order-driven systems. In contrast, using mutable support structures and modularity increases manufacturing flexibility, thus reducing the problems associated with internal variety. These strategies are, hence, most effective before customization and add greatest value in an order-driven system.

While many solutions have been proposed for managing product variety, their effectiveness depends on the order-to-delivery model for the product line. The first question managers should consider is whether existing order-fulfillment strategies suffice for the firm's various product families. For example, in some instances a product family does not need customization or is designed for customizing by customers (as is the case for adjustable office chairs). For such products, build-to-forecast systems may work well.

For products the firm customizes and holds in stock, the firm risks their obsolescence or costs for holding inventory exceeding demand (for example, discounts). External variety may not be a major issue if inventory levels are sufficiently low, as it is for fast-moving consumer goods, such as canned soup or fruit juice. However, if the firm provides a high level of external variety in its products, a forecast-driven model poses problems.

Once a firm chooses a forecast-driven model, the efficiencies and economies of scale it can achieve are critical, favoring late configuration and option bundling. If it chooses an order-driven value chain, it should try to create mutable support structures and modular architectures. In some instances, firms can start with strategies to manage variety and work

	Mutable support structures	Modularity	Late configuration	Option bundling
Forecast-driven value chain (postcustomization)	Economy of scale advantages only.	Moves complexity offline, outsourcing potential.	Increases choice without increasing fundamental variety.	Reduces forecast error and inventory risk.
Order-driven value chain (precustomization)	Increases flexibility in the manufacturing process to enhance ability to respond to customer needs.	Increases responsiveness and manufacturing flexibility. Moves complexity offline.	Enables possible reduction of internal variety, and reduces impact of first-time-OK problems.	No significant advantage. Some opportunities for error reduction in assembly.

Table 4: Strategies that reduce the impact of variety in forecast-driven value chains have very different implications in order-driven (build-to-order) contexts. First-time-OK relates to the fraction of vehicles that make it through the production process without requiring rework.

towards a novel order-delivery mode. For example, by leveraging mutable support structures, firms may be able to increase customers' choices among attributes.

Some firms leveraging mutable support structures have transformed their industries. For example, Dell pioneered a build-to-order model in the computer sector, giving its customers unprecedented choice on desktop computers destined for home use. Customers can select among six processors, four different memory levels, three hard drives, combinations of seven different removable media storage and playback devices (in 32 different configurations), three keyboards, two mice, four video cards, two modem types, and two different network options for a total of 221,184 configurations, not including a number of software and accessory choices. Dell still recommends three basic configurations (entry, mid-level, and high-level) for desktop models for home use to help customers who might be overwhelmed by all the choices offered, but its pioneering strategy of building to order has helped it to dominate its industry. Firms that pioneer leveraging a customer-driven value chain can develop a sustainable advantage over those that are not as rapid in moving away from forecast-driven models.

Concluding Thoughts

Our findings provide firms with insight for managing product variety, and our conclusions reach beyond the automotive industry. Contrary to common perception, no direct link lies between the level of choice a firm offers its customers and complexity in manufacturing. The success of any strategy aimed at mitigating the costs and complications of producing product variety depends upon what order-fulfillment strategy the firm follows. A misaligned mitigation strategy may be futile or may even hurt the system. Using an option-bundling strategy in a build-to-order environment, for example, benefits factory operations very little and may restrict customer choice.

Our examination of external and internal variety provides a static picture of a product's variety; we did not examine the dynamic aspect of product variety. The more product generations a firm offers over time, the more effective variety it offers to its customers. In the auto sector, the average life from introduction of vehicle models to replacement or major facelift has been steadily declining. Future studies might explore the implications of these transformations from a manufacturing and order-to-delivery standpoint. For example, the mutable support structures that help firms to manage internal variety in build-to-order systems may also help them to increase dynamic variety.

We have considered strategies that mitigate the negative effects of providing product variety individually, not their interactions. For example, when a firm's support structures are immutable, by offering options in discrete bundles, the firm can reduce the complexity in building products to order or to forecast. We have also only begun to address some important value-chain considerations. For example, the auto industry often pairs modularity with outsourcing and colocated suppliers without really understanding this shift in production responsibility and its implications for managing internal variety. Likewise, the risks associated with expanding mutability to encompass support structures across product lines can be significant, because the benefits of mutability may be offset by losses of product uniqueness. Relating internal and external variety to order-to-delivery mechanisms offers exciting opportunities for research and management of product variety.

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