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Modularity and the Impact of Buyer–Supplier Relationships on the Survival of Suppliers

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Modularity in product design and flexible supply chains is increasingly common in buyer–supplier relationships. Although the benefits of supply chain flexibility and component modularity for end-product manufacturers are accepted, little is known about their impact on suppliers. We advance the literature on modularity by exploring how three aspects of a supplier's relationships with its customers affect the supplier's survival: duration of buyer–supplier relationships, autonomy from customers, and links to prominent buyers. We compared the effects of these aspects of buyer–supplier relationships for low- and high-modularity components. Using data on U.S. carburetor and clutch manufacturers from 1918 to 1942, we found that suppliers of high-modularity components benefited more from autonomy provided by potential customers, whereas suppliers of low-modularity components benefited more from ties to higher status customers. Both benefited from autonomy generated by existing customers. Thus, relationships that require trust and extensive sets of interfirm routines, as do those for low-modularity components, led to both greater relationship benefits and greater constraints.

Key words: modularity; buyer–supplier relationships; status; autonomy; relationship duration
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The evolution of many industries over the past century has been characterized by two related phenomena in buyer–supplier relationships: increasingly modular products and a shift to more flexible, disaggregated supply chains (Langlois and Robertson 1992, Zenger and Hesterly 1997, Schilling and Steensma 2001). Components that exhibit low modularity require customization to fit in a customer's product and, indeed, may also require adaptation of the customer's product to fit the component's technology. By contrast, highly modular components can be incorporated into multiple end products with little component or end-product change (Schilling 2000). Increasing component modularity facilitates supply chain flexibility by reducing the need for specialized interfaces between an end-good producer and component suppliers (Sanchez and Mahoney 1996). This trend raises the issue of how different aspects of relationships with buyers influence supplier performance, which has been a long-standing interest of business strategy research (Martin et al. 1998, Dyer 1996a).

Differences in supply relationships can affect the performance of both buyers and suppliers. Clearly, component modularity and the resultant supply chain flexibility can improve the performance of buyers (Vickery et al. 1999, Mikkola 2003). Component modularity improves a buyer's ability to drop, add, or change suppliers in response to changing conditions (Garud and Kumaraswamy 1995, Galunic and Eisenhardt 2001). Rather than being locked into preexisting relationships, a buyer can choose the best supplier at any point (Hoetker 2006, Ulrich 1995). Because a buyer can consider a larger number of suppliers, it can consider the outcomes of multiple experiments in how to construct each component, which increases the expected value of the approach that the buyer selects (Ethiraj and Levinthal 2004, Langlois and Robertson 1992).

However, it is not immediately obvious how buyers' enhanced ability to switch suppliers affects the latter. On the one hand, a supplier's bargaining position weakens when it is easier for a buyer to walk away. On the other hand, if all buyers can switch suppliers easily, a supplier may be able to find a new buyer easily. The end result is ambiguous. Given the impact of buyer–supplier relationships on firms and industries (Clark and Fujimoto 1991), it is important to understand how component modularity affects supply chain relationships.[1]

We study how modularity shapes three aspects of a supplier's buyer relationships that prior research suggests may influence supplier survival: the duration of relationships with buyers (Levinthal and Fichman 1988), autonomy from buyers (Burt 1992), and links to prominent buyers (Podolny 1993). We advance the modularity literature by examining how the degree of modularity of the product exchanged in a buyer–supplier relationship conditions the influence of each aspect. We also contribute to the literature on interfirm relationships by showing that the benefits and constraints of a firm's relationships derive in large part from the needs of the relationships, including trust and the type of interfirm coordination routines required. We find that relationships requiring trust and routines to be extensive tend to have greater benefits and constraints than those that require less trust and less extensive routines. Furthermore, relationship structure is more important for buyer–supplier connections that require high trust and extensive coordination. The study examined carburetor and clutch suppliers in the U.S. auto industry from 1918 to 1942. Clutches were more modular than carburetors throughout this period. The data were based on all buyer–supplier relationships in the populations of component suppliers and automobile assemblers during the period.

Theory and Hypotheses

In this section, we develop arguments concerning how duration, autonomy, and buyer prominence influence supplier survival. Although multiple streams of the interfirm relationship literature have examined these factors, the role of modularity has received little conceptual or empirical attention, and we are unaware of any study of supplier performance that has addressed these three aspects jointly.

A component is modular to the extent that it can be incorporated into a product without needing to be changed or requiring the rest of the product to be changed. Components with low modularity require customization to fit in a customer's product or adaptation of the customer's product. By contrast, components with high modularity can be incorporated into multiple end products with little component or end-product refinement (Schilling 2000). Modularity is a continuous concept, but we will simply refer to components that stand far apart in this spectrum as having *low modularity* or *high modularity*.

Duration of Buyer–Supplier Relationships and Supplier Survival

A long-term relationship generates value for both a buyer and a supplier. The supplier benefits directly by capturing some of this value and indirectly from the enhanced likelihood of continued business from the buyer, which gains a competitive advantage from the efficiencies of the relationship.

The value of a long-term supply relationship arises from the development of mutual knowledge of partners' capabilities and routines (Ring and Van de Ven 1994), trust between partners (Gulati 1995), and relationship-specific routines for the coordination of partners (Mitchell and Singh 1996, Asanuma 1989). These three factors create value in multiple ways. Communication and coordination can lead to a superior product that can be sold at a premium price (Dyer 1996b). In addition, communication, coordination, and lower governance costs resulting from trust translate into lower component costs (Dyer 1996b, Uzzi 1997), which can increase sales by lowering the price of the final product and can increase the margin between production cost and sales price. Suppliers may benefit by directly capturing some of the value created by the relationship (Dussauge et al. 2000).

A supplier in a long-term relationship with a buyer also benefits from the enhanced likelihood of continued business from the buyer, which will be less likely to leave the supplier because of the value generated by the relationship's competitive advantages (Eccles 1981, Simon 1969). In addition to the benefits of continued custom, the supplier may be able to extract more favorable conditions in negotiations with the buyer, given the latter's low willingness to leave the supplier (Williamson 1985).

However, a long-term relationship will promote supplier survival only to the degree that its benefits are relevant and value-creating, outcomes that, we argue, are contingent on the modularity of the component being traded. We expect the value of a long-term relationship to be greater for low-modularity components. The supply of low-modularity components requires the relationship-specific knowledge, trust, and routines that flow from long-term relationships because of the need for ongoing interaction between buyer and supplier to achieve customization

[1] Modularity sometimes reflects the design choices made for a specific firm's product (Baldwin and Clark 2000), but similar degrees of modularity commonly characterize a component, product, and system, reflecting the underlying physics of the component, the current state of technological development, and the level of industry-wide standardization (see, e.g., Langlois and Robertson 1992). Our focus was on the situation in which all buyers and suppliers face a similar state of modularity for a type of component.

and mutual adjustments. As a supplier provides low-modularity components to a buyer over time, these benefits cumulate and generate value.

By contrast, supplying high-modularity components requires general investments that are more transparent and derive less benefit from relationship-specific knowledge, trust, and routines. Thus, a long-term relationship generates less value and consequently less benefit for suppliers of highly modular components. Less value is available for a supplier to capture, and the supplier has both less assurance of continued custom from a long-term buyer and less advantage in negotiations with the buyer.

Theory and prior empirical work are unclear as to whether greater benefits are gained from a single long-term relationship or from a portfolio of such relationships. A primary relationship with one long-term partner, possibly supplemented with shorter relationships with other buyers, may provide a strong foundation for supplier success, as exemplified by a supplier that has a primary long-term relationship within the *keiretsu* of a Japanese automotive manufacturer (Asanuma 1989). Alternatively, suppliers may benefit most if they have long-term relationships with several buyers that provide a varied base of knowledge, trust, and routines. We tested both aspects of relationship duration.

We make no main effect prediction for duration and survival because it is theoretically ambiguous at what level of modularity duration ceases to have a discernable effect on supplier survival. Nonetheless, theory leads to a clear comparative hypothesis:

Hypothesis 1. *Relationship duration will reduce the failure rates of suppliers of low-modularity components more than the failure rates of high-modularity component suppliers.*

We recognize that long-term relationships may also give rise to constraints. Recent work has drawn attention to potential limitations of strong interorganizational ties (e.g., Gargiulo and Benassi 2000). These limitations include the development of cognitive "lock-in," which filters out information from beyond the relationship, and relational inertia, which makes organizations reluctant to terminate relationships, even if their value declines. The hypothesis reflects the most common argument in prior research, but the analysis will help assess whether the benefits outweigh the constraints.

Supplier Autonomy and Performance

We continue by considering a supplier's autonomy relative to its customers. Early work on this aspect of interfirm relationships has focused on a firm's dependence on other organizations for resources (Pfeffer and Salancik 1978, Cook 1977, Emerson 1962). Much of the more recent work has instead highlighted *autonomy*, which is the degree to which a supplier can act independently of its buyers (Burt 1992).

A supplier's autonomy in its dealings with a buyer stems from the difference between how dependent it is on the buyer and how dependent the buyer is on it (Burt 1992). A supplier will be highly dependent on a buyer if it sells only to that buyer and would experience difficulty finding an alternative buyer for its output (Pfeffer and Salancik 1978). However, this dependency can be balanced by the buyer's dependency on the supplier (Cook 1977). Such dependency exists if the buyer has no alternative sources for the components that the supplier provides or if the firms have formed complex routines that span their boundaries, making it difficult for the buyer to replace the supplier easily (Baker 1990, Singh and Mitchell 1996). A supplier with a single buyer that cannot obtain the supplier's component elsewhere may be in a better position than a supplier with several buyers that can all easily switch to alternative suppliers.

We predict that suppliers lacking autonomy from their buyers will face performance problems that stem from opportunistic behavior by the buyers. Although specialization economies are available when a supplier is tightly bound to a buyer, the accompanying lack of autonomy makes the supplier vulnerable. The buyer may use its power to extract rents from the supplier, limit the supplier's ability to sell goods to other buyers, or otherwise constrain the supplier (Baker 1990, Williamson 1993). Financial problems at the DaimlerChrysler automotive firm during 2001, for instance, led the company to press its dependent suppliers. Suppliers that had benefited from close relationships with Chrysler found themselves facing failure as they were forced to cut prices.

In addition, because having a range of buyers generates supplier autonomy, a supplier with high autonomy will be harmed less by losing a given buyer's business. Furthermore, because buyers having few options for supply also generates supplier autonomy, a supplier with high autonomy may be less likely to lose a given buyer's business.

We refer to autonomy based on the balance between how dependent a supplier is on its current buyers and how dependent those buyers are on it as *current autonomy* to distinguish it from *potential autonomy*, which we discuss below. We expect current autonomy to benefit most suppliers, although it is unclear whether it will be of greater benefit to suppliers of low-modularity or high-modularity components. High current autonomy should provide all suppliers greater sales opportunities and help them resist the demands of a few buyers. The strongest effect might accrue to suppliers of low-modularity products, owing to the need for relation-specific routines.

On the other hand, a supplier of a high-modularity component can sell it to multiple customers with minimal modification, creating greater economies of scale than is possible with a low-modularity product. We examine this issue empirically.

A supplier's potential autonomy measures its opportunities to form ties to new buyers—buyers with which it does not currently trade—relative to the buyers' opportunities to develop ties to new suppliers. The presence of potential buyers beyond those with which a supplier already trades increases its available alternatives. Even if a supplier has only one buyer, it is better off if there are 10 buyers to which it could start selling than if there is only one other potential buyer.[2] The potential autonomy of a supplier is high when it has many buyers available outside its current set of buyers and its buyers have few alternatives outside of their current suppliers.

We expect the benefits of potential autonomy for suppliers to increase with increasing modularity. The availability of potential partners strengthens a firm's bargaining position only to the degree that they are credible alternatives to existing partners. Low-modularity components require relation-specific coordination (Monteverde and Teece 1982), meaning that buyers and suppliers cannot easily switch partners, even if many other seemingly potential suppliers and buyers exist.

By contrast, high-modularity components generate fewer requirements for relation-specific coordination, so buyers and suppliers can switch partners more easily. The greater availability of potential partners helps mitigate the threat of opportunism. Also, it is easier for suppliers of high-modularity inputs to find new buyers because switching costs are low.

Hypothesis 2. *Potential autonomy will reduce the failure rates of suppliers of high-modularity components more than the failure rates of suppliers of low-modularity components.*

Customer Status and Supplier Survival

It is often difficult for buyers to evaluate the quality of a potential supplier's products. Lacking complete information about the supplier's technical sophistication, reliability, and quality, they frequently look for secondary indicators (Podolny 1993). Because buyers often trust the ability of high-status buyers to judge the quality of their suppliers, potential buyers may imitate the supplier choices of such prominent buyers (Stuart 1998).

[2] Although market structure influences autonomy, two suppliers in the same market could have different autonomy levels, depending on their relationships with customers and the customers' other relationships.

Walker et al. (1997) found empirically that biotechnology firms with higher status had more subsequent relationships with new partners (see also Powell et al. 1996). Similarly, Baker et al. (1998) found that advertising agencies with higher social status maintained client links. Not surprisingly, multiple studies have shown that ties to high-status partners improve performance and survival (Stuart et al. 1999, Rockart 2003).

We argue that buyers are more influenced by the status of a supplier's other customers when the supplier provides a low-modularity component because ambiguity about the supplier's quality is higher (Podolny 1993). A buyer of a low-modularity component must assess both the quality of a supplier's component and the supplier's ability to make the changes needed to integrate it into the buyer's product. The latter is hard to assess in advance, leading buyers to rely on high-status customers' judgments as a signal of supplier quality. In contrast, a buyer of a high-modularity component has less need to judge the ability of a supplier to adapt its component because integrating it into the buyer's product will not require extensive changes. Thus, buyers can determine a supplier's quality directly by examining the components it produces and have less need to rely on the judgment of prominent customers before entering into a relationship.[3]

In addition, a buyer can more easily abandon a poor supplier of a high-modularity component, which needs less relation-specific coordination, than a poor supplier of a low-modularity component. Because of the difficulty of switching suppliers of low-modularity components, buyers value information about suppliers' quality more highly, including the status of its customers.

Thus, suppliers of low-modularity components can benefit from the strong signal of quality generated by affiliation with a high-status buyer. Again, we have no hypothesis for the main effect of customer status but make the following comparative hypothesis:

Hypothesis 3. *Customer status will reduce the failure rates of suppliers of low-modularity components more than the failure rates of suppliers of high-modularity components.*

Data and Methods

We studied the survival of U.S. suppliers of carburetors and clutches in the auto industry. We chose these components for several reasons: Their degree of modularity differed significantly, they were important inputs in automobile production, and the firms that manufactured them showed substantial diversity. The annual statistics and specifications issue of *Automotive Industries*, which was produced from 1918 to 1972,

[3] A reviewer thoughtfully noted that this logic echoes the signaling literature (Spence 1973, Nelson 1970).

was our primary data source. The analysis focused on the 1918 to 1942 period, because there were few firms in the component sectors that we studied after the Second World War.

Automotive Industries listed first-tier suppliers—firms that sold components directly to assemblers—by automobile model. Because the publication provided specifications at the level of a division or model without listing overarching companies, we used information from *Automobile Quarterly* (1971), Smith (1968), Mandel (1982), Gunnell (1982), and Kimes (1989) to construct life histories of assemblers and to connect divisions and models to parent companies. After aggregating the data to the firm level, we constructed a matrix of ties between supplier firms and buyer firms for carburetors and clutches for each year. *Automotive Industries* professed to list every model of automobile produced in the United States. This comprehensiveness allowed us to create a complete inventory of buyer–supplier relationships for these components.

We gathered information about the performance and life histories of suppliers from several sources, including corporate annual reports, *Poor's Industrial Manual*, *Moody's Manual of Industrial Securities*, the *Thomas Register of American Manufacturers*, *Ward's Automotive Yearbook*, the trade press, corporate Web sites, and correspondence with suppliers. The statistics and specifications issue of *Automotive Industries* provided information on annual shipments for assemblers of at least medium size. We supplemented this information with data from the *Automotive News 100-Year Almanac and 1996 Market Data Book* (1996).

Carburetors were our low-modularity product, and clutches were our high-modularity product. Carburetor design and production required customization to and of ignition systems, fuel systems, power trains, and other sections of automobiles. Carburetors were complex, unstandardized goods throughout the study period (Page 1918, Dyke 1923). As Newcomb and Spurr (1989, p. 64, emphasis added) noted, "[E]ven in the 1960s, the design of the system was still very much a matter of trial and error, and *the final design largely a matter of compromise. A layout that could suit one engine might give poor results on another*." An early account emphasized that "[s]ome elements of carburetor design concerned with adaptability to a given engine or to operating conditions of a given engine or to a given fuel ... may not be brought out by the study of proportions alone, or to study flow alone, or even to any particular sort of pulsating flow. These are all matters worthy of careful consideration, but somewhat intangible and elusive in character" (Lucke and Willhöfft 1917, pp. 64–65). Thus, the design and manufacturing processes required a considerable degree of give and take between supplier and buyer.

Clutches, by contrast, had achieved high modularity and become relatively standard by the beginning of the period. Even before 1920, Page (1918, p. 635) noted that "friction clutches are simple in form, easily understood, and may be kept in adjustment and repair without difficulty." The relatively simple single-plate clutch quickly became the choice of most automobile manufacturers and required little customization for specific automobile models (Dyke 1923). Newcomb and Spurr (1989, p. 221) stated that "once established [by about 1919] the basic principles of the clutch remained unchanged for many years, though there was considerable improvement in the detail design."

Dependent Variable and Statistical Method

We defined *supplier failure* as a supplier shutting down its production in the automotive carburetor (clutch) market. We estimated the hazard rate (the instantaneous rate of supplier dissolution) using a piecewise exponential model. The model was flexible with respect to the form of age dependence and appropriate in the presence of "left censoring" (Guo 1993, Barnett and Hansen 1996), which occurred in our sample. The hazard rate for a given supplier i at age t, given covariates $\mathbf{X}_{it}$, was

$$r_i(t) = \alpha_i r(t) \exp(\mathbf{X}_{it}\boldsymbol{\beta}). \tag{1}$$

The model's assumption was a baseline transition rate, $r(t)$, that was constant across all suppliers of age t but varied over age ranges. We used three age ranges in our estimation, dividing the data into firm ages of less than 5 years, 6 to 10 years, and greater than 10 years. The results were robust to selecting other cutoff points as well as to using other parametric forms of age dependence in the mortality rate, including the Weibull, log-logistic, and lognormal specifications.

Because we observed multiple annual spells for each supplier i, we used a shared frailty model (Gutierrez 2002), in which it is assumed each supplier may have had a systemically lower or higher rate of failure for reasons not explained by the covariates. This difference was captured in Equation (1) by the term α_i, a random positive quantity with a mean of 1 and variance of θ, orthogonal to the observed covariates. Suppliers for which this quantity was greater than 1 had an increased rate of failure (were more frail) for reasons not explained by the covariates. Those with a value of α_i less than 1 had a decreased rate of failure. This model provided the survival analysis analogue to a random-effects model in standard regression. We report models with a gamma-distributed heterogeneity term with probability density function,

$$g(\alpha) = \frac{\alpha^{1/\theta-1} \exp(-\alpha/\theta)}{\Gamma(1/\theta)\theta^{1/\theta}}. \tag{2}$$

We also estimated models with an inverse Gaussian distribution for the heterogeneity term to check for robustness.

Our data were annual, so we updated time-varying covariates each year. We treated all annual spells as right-censored except those that ended with dissolution of the supplier. We treated dissolutions as occurring midway though the year to reduce estimation bias (Peterson and Marsden 1991). We treated divestitures that occurred during the study period (11 carburetor and 6 clutch suppliers were affected) as censoring events.

Separate failure rate models were estimated for carburetor and clutch suppliers. Combining the two populations would have mistakenly constrained the effects of firm- and industry-level variables to be equal for the populations. Two firms made both components. Given our sample size and the small proportion of firms involved, we did not control for their presence in both populations. For carburetor suppliers, there were 225 firm-year observations (35 separate carburetor suppliers) between 1918 and 1942, with 24 dissolutions. For clutch suppliers, there were 130 firm-year observations (30 separate clutch suppliers) between 1918 and 1937, with 23 dissolutions. These counts did not include assemblers that vertically integrated into production of the components. Our calculations of current and potential autonomy took those assemblers into account, but we did not include them in the supplier populations because the forces driving their involvement in component production differed from those driving the independent suppliers.

Focal Independent Variables

Relationship Duration. We measured the duration of a supplier's relationship with an assembler as the cumulative years it supplied the given component for at least one model produced by that assembler. We reset this count to 0 if there was a span of greater than five consecutive years during which the supplier did not supply a component for at least one model produced by that buyer. Resetting the count captured the effect of the decay of relation-specific routines and trust. In the case of an acquisition by either a supplier or an assembler, we based our calculations on the acquiring firm, assuming its routines would dominate.

We used two measures of duration. *Maximum duration of customer relationship* recorded the longest single relationship a supplier had with any current customer. *Average relationship duration* recorded the mean length of all of the supplier's current relationships.

Autonomy. Building on Cook and Emerson (1978), Pfeffer and Salancik (1978), Emerson (1962), and Burt (1980), our measure of autonomy captured two factors: (1) The more alternatives available to a firm, the less dependent it was on any given partner; and (2) the power of firm A over firm B depended on the difference between A's dependence on B and B's dependence on A. We measured the *current autonomy* of a supplier as the ratio of the number of assemblers to which it sold to the mean number of suppliers its customers had. This variable captured the relative dependence of the supplier on its current buyers. We measured the *potential autonomy* of a supplier as the ratio of the number of existing assemblers to which it did not sell to the mean number of existing suppliers from which its customers did not buy. This variable captured the relative abilities of a supplier and its buyers to create new ties.

We measured autonomy using ratios because it is an inherently relative concept. Our interest was not whether a supplier had three or six customers; instead, our interest was whether it had twice or only half as many trading partners as its customers did.[4]

We also defined a complementary measure of autonomy, based on customer vertical integration. An assembler can replace a supplier by vertically integrating production of the component the supplier provided. Therefore, we included the proportion of a focal supplier's customers that were vertically integrated as a measure of autonomy. When this value is high, the supplier has less autonomy, and we thus expected a high proportion of vertically integrated customers to increase suppliers' dissolution rates.

Correlations among the three measures of autonomy were low and often negative. The data, therefore, supported treating autonomy as a multidimensional construct, as we did in our theoretical development.

Maximum Customer Status. We measured status in terms of a supplier's highest status buyer, which would be the focus of other firms' search for information about the supplier's capabilities. The fact that a highly respected assembler chose a firm to supply components acts as a strong signal of that supplier's skills.

We measured customer status according to three categories prominent in the automobile industry during the study period. The contemporary literature clearly indicated that there were three distinct groups of assemblers by 1918: (1) the major assemblers (Ford, General Motors and, following the acquisition of Dodge, Chrysler); (2) the major independents, which were referred to by that term (e.g., Hudson and

[4] Measuring sales volume would have provided a finer-grained measure of autonomy, but we are unaware of any large-scale, longitudinal study that uses sales data as a measure of interfirm relationships, because such data are not accessible. Following other work (such as the arguments in Baker et al. 1998 for their Hypotheses C1 and C4), we used a measure based on number of buyers and suppliers.

Packard); and (3) the minor independents (all others, e.g., Dort and Geronimo). We assigned each assembler to one of the three status categories using Kennedy's (1941) year-by-year commentary. From early on, the major assemblers stood apart in their impact on industry evolution and in their economic success. In 1919, for example, they were the only three producers with net incomes over $10 million: Ford with $69 million, General Motors with $60 million, and Dodge with $24 million (Kennedy 1941, p. 105). The major independents had a lesser, but still significant, presence in the industry. Kennedy (1941, p. 81) made the point clearly: "The history of the automobile industry has been the history of not more than twenty companies." The minor independents were the other auto producers, many of which "now have no more than an antiquarian interest and their significance was never great" (Kennedy 1941, p. 84).

As a check, we compared these categorizations with descriptions in other contemporary texts. The status categorization of assemblers changed only slightly over time. Three assemblers spent several years straddling two categories. Our results were robust to moving these three assemblers between the higher and lower of their possible status categories. We denoted status with two dummy variables: *medium status* (major independents) and *high status* (major assemblers).

Control Variables

We defined several firm- and industry-level control variables.

Aggregate Customer Production. The aggregate customer production variable recorded the total unit production of all of a supplier's customers in a given year. Ideally, we would have recorded supplier-specific sales to customers, but data about how many clutches or carburetors each supplier sold to each assembler in a given year did not exist. However, suppliers that sold to large assemblers such as GM and Ford would have tended to have greater aggregate sales than suppliers that sold components only to much smaller firms such as Dort and Geronimo.

Supplier Size. We took our measure of supplier size from the *Thomas Register of American Manufacturers*, which reports firm capitalization. Suppliers in our sample ranged from size E (capitalization of $5,000–$9,999) to AAAA (a rating higher than $1,000,000). Our size variable, *large supplier,* equaled 1 if a supplier was in category AAA ($500,000–$1,000,000 capitalization) or higher, and 0 otherwise.

The variables for customer production and supplier size helped differentiate the benefits of scale from the benefits of customer status. Although high-status customers also tended to be large firms, suppliers serving assemblers of similar status varied considerably in the total production of the assemblers they served, thus achieving different economies of scale. If the only benefits of serving high-status customers came from customer scale, this effect would have been captured by the aggregate production of all of a supplier's customers and by supplier size.

Firm Age. We created age variables, which are common in studies of business failure. We measured supplier age as the number of years elapsed since a firm's birth. When that information was not available, generally for smaller suppliers, we generated a random date of birth between the year when the earliest suppliers appeared (1903 for clutches, 1907 for carburetors) and 1917, the year prior to the beginning of our observation period. We included a dummy variable indicating the 14 carburetor suppliers and 9 clutch suppliers with randomized founding dates to allow for the possibility that their hazard rate differed systemically from that of other suppliers.

Including supplier age and size helped address an alternative argument, which is that a supplier's capabilities are the primary cause of its survival. Historical longitudinal studies of business survival, for which fine-grained measures of capabilities are typically not available, commonly use business age and size as measures of capabilities to address this argument (Hannan 1998), on the assumption that firms with stronger capabilities become older and larger than firms with weak capabilities. Our use of these firm-specific variables in combination with the shared frailty specification addressed the alternative argument that unobserved firm-specific capabilities may produce differential survival chances.

Competition and Demand. Finally, we created two variables to assess competitive and demand conditions. We measured competition as competitor density, using the number of suppliers of a component in a given year. Drawing on empirical work in organizational ecology, we also included the square of this term in sensitivity analysis. On the demand side, we included annual total U.S. auto production, using data from *Historical Statistics of the United States* (United States Bureau of the Census 1989).

Table 1 provides descriptive statistics. There was no evidence of problematic multicollinearity. For carburetors, the mean variance inflation factor (VIF) was 2.07 and the maximum VIF, 3.67. For clutches, the mean VIF was 2.49 and the maximum, 4.85. All values were well below 10, the conventional benchmark.

Results

Table 2 reports the results of the analysis of carburetor and clutch supplier failure. The variance of the unobserved heterogeneity parameter, θ, does not differ significantly from 0 in any model, indicating that

Table 1 Descriptive Statistics and Product–Moment Correlations

	Mean	SD	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Carburetor suppliers (225 cases)																			
(1) Supplier age <5 years	0.22	0.41	0.00	1.00	1.00														
(2) Supplier age between 5 and 10 years	0.19	0.39	0.00	1.00	−0.25	1.00													
(3) Supplier age greater than 10 years	0.60	0.49	0.00	1.00	−0.64	−0.58	1.00												
(4) Density (no. of firms in industry)	11.02	4.22	3.00	19.00	0.13	0.15	−0.22	1.00											
(5) Unknown founding date	0.34	0.48	0.00	1.00	−0.18	0.14	0.04	0.32	1.00										
(6) Large supplier (Thomas register rating of AAA or better)	0.47	0.50	0.00	1.00	−0.11	−0.11	0.18	−0.57	−0.34	1.00									
(7) Agg. prod. of cust. (millions)	0.63	0.87	0.00	3.79	−0.14	−0.01	0.13	−0.39	−0.29	0.44	1.00								
(8) Total national sales/1,000	2.60	1.06	0.22	4.46	−0.07	−0.17	0.19	−0.28	−0.18	0.24	0.37	1.00							
(9) Mean duration of cust. relationship	4.31	3.78	0.00	22.00	−0.46	−0.08	0.45	−0.09	−0.00	0.18	0.07	−0.00	1.00						
(10) Max. duration of cust. relationship	7.28	6.07	0.00	24.00	−0.53	−0.14	0.56	−0.07	−0.06	0.24	0.15	0.07	0.82	1.00					
(11) Current autonomy	3.92	6.60	0.25	45.18	−0.19	−0.01	0.17	0.18	−0.03	0.03	0.10	−0.11	0.03	0.28	1.00				
(12) Potential autonomy	5.03	2.22	0.58	9.83	0.17	0.19	−0.30	0.59	0.24	−0.56	−0.46	−0.30	−0.14	−0.19	−0.10	1.00			
(13) Prop. of vertically integrated cust.	0.09	0.19	0.00	1.00	0.13	−0.02	−0.09	0.08	−0.18	−0.06	0.20	0.09	0.05	−0.01	−0.12	0.19	1.00		
(14) Maximum customer status = medium	0.30	0.46	0.00	1.00	−0.16	−0.16	0.26	0.06	0.04	−0.07	−0.36	0.13	0.11	0.22	0.18	0.02	−0.18	1.00	
(15) Maximum customer status = high	0.48	0.50	0.00	1.00	−0.08	0.17	−0.07	−0.26	−0.08	0.31	0.65	−0.01	0.11	0.06	−0.01	−0.21	0.38	−0.63	1.00
Clutch suppliers (130 cases)																			
(1) Supplier age < 5 years	0.29	0.46	0.00	1.00	1.00														
(2) Supplier age between 5 and 10 years	0.20	0.40	0.00	1.00	−0.32	1.00													
(3) Supplier age greater than 10 years	0.51	0.50	0.00	1.00	−0.65	−0.51	1.00												
(4) Density (no. of firms in industry)	11.15	4.73	3.00	18.00	−0.13	−0.04	0.15	1.00											
(5) Unknown founding date	0.22	0.42	0.00	1.00	−0.26	0.15	0.12	0.38	1.00										
(6) Large supplier (Thomas register rating of AAA or better)	0.42	0.50	0.00	1.00	0.07	0.12	−0.15	−0.31	0.21	1.00									
(7) Agg. prod. of cust. (millions)	0.28	0.70	0.00	3.79	0.00	0.21	−0.17	−0.37	−0.19	0.20	1.00								
(8) Total national sales/1,000	2.59	1.06	0.94	4.46	0.08	−0.26	0.13	−0.24	−0.24	0.19	0.22	1.00							
(9) Mean duration of cust. relationship	1.15	1.56	0.00	7.00	−0.19	0.08	0.12	−0.38	−0.27	0.02	0.59	0.40	1.00						
(10) Max. duration of cust. relationship	1.72	2.18	0.00	10.00	−0.21	0.06	0.15	−0.34	−0.31	−0.00	0.64	0.42	0.90	1.00					
(11) Current autonomy	5.36	10.42	0.50	60.02	−0.13	0.33	−0.15	−0.05	−0.21	−0.13	0.37	−0.07	0.23	0.36	1.00				
(12) Potential autonomy	6.63	2.51	0.53	13.00	−0.07	−0.10	0.14	0.08	0.21	−0.14	−0.61	−0.38	−0.52	−0.56	−0.42	1.00			
(13) Prop. of vertically integrated cust.	0.13	0.29	0.00	1.00	0.25	−0.16	−0.10	0.08	0.06	0.13	0.11	0.12	−0.08	−0.08	−0.08	−0.11	1.00		
(14) Maximum customer status = medium	0.15	0.35	0.00	1.00	0.16	0.23	−0.33	−0.11	−0.12	0.22	−0.08	0.19	−0.09	0.01	0.27	−0.15	0.04	1.00	
(15) Maximum customer status = high	0.17	0.38	0.00	1.00	0.16	0.03	−0.17	−0.20	−0.14	0.07	0.79	0.04	0.42	0.48	0.38	−0.50	0.32	−0.19	1.00

Table 2 Piecewise Exponential Model of Supplier Failure Rates

	Carburetors (low modularity)				Clutches (high modularity)			
	1a	1b	1c	1d	2a	2b	2c	2d
Supplier age <5 years	−2.041	−1.752	0.034	0.468	−1.918*	−1.811*	2.200	2.172
	[1.405]	[1.443]	[1.663]	[1.861]	[1.003]	[0.987]	[1.843]	[1.939]
Supplier age between 5 and 10 years	−2.207	−1.071	1.154	1.618	−4.055**	−3.749**	0.952	1.280
	[1.489]	[1.533]	[1.741]	[1.875]	[1.126]	[1.130]	[1.951]	[2.029]
Supplier age greater than 10 years	−3.783**	−2.382	−0.456	0.393	−3.562**	−3.221**	1.045	1.108
	[1.594]	[1.561]	[1.809]	[1.892]	[1.104]	[1.096]	[1.922]	[1.990]
Competitor density (number of firms in industry)	−0.012	0.021	0.072	0.018	0.037	0.022	0.017	0.005
	[0.079]	[0.071]	[0.068]	[0.078]	[0.057]	[0.058]	[0.061]	[0.062]
Unknown founding date	1.008	0.777	0.766	0.905	1.691**	1.572**	0.997	0.862
	[0.814]	[0.550]	[0.627]	[0.659]	[0.630]	[0.641]	[0.668]	[0.672]
Large supplier (Thomas register rating of AAA or better)	−0.504	−0.308	−0.446	−0.439	−0.439	−0.555	−0.143	−0.025
	[0.612]	[0.592]	[0.588]	[0.621]	[0.493]	[0.515]	[0.513]	[0.529]
Aggregate production of customers (millions)	−1.132*	−0.894	−1.481*	−0.415	−0.829	−0.546	0.125	−1.282
	[0.605]	[0.558]	[0.779]	[0.875]	[0.905]	[0.853]	[1.703]	[2.515]
Demand (National auto production in millions)	0.461	0.237	0.046	0.045	0.262	0.360	0.074	0.226
	[0.303]	[0.263]	[0.284]	[0.302]	[0.245]	[0.259]	[0.274]	[0.332]
Maximum duration of customer relationship		−0.271**	−0.121*	−0.099		−0.267	−0.013	−0.066
		[0.094]	[0.086]	[0.089]		[0.234]	[0.212]	[0.220]
Current autonomy			−1.402**	−1.429**			−2.078**	−2.192*
			[0.479]	[0.505]			[0.745]	[0.776]
Potential autonomy			−0.152	−0.059			−0.223*	−0.243*
			[0.151]	[0.165]			[0.146]	[0.152]
Proportion of vertically integrated customers			1.821*	1.978			0.136	−0.086
			[1.209]	[1.263]			[0.606]	[0.680]
Maximum customer status = medium				−1.868**				−0.191
				[0.838]				[0.838]
Maximum customer status = high				−1.815**				1.149
				[0.961]				[1.356]
Observations	225	225	225	225	130	130	130	130
Log-likelihood	−28.37	−22.61	−12.43	−7.99	−14.36	−13.65	−2.66	−2.20
Incremental log-likelihood chi-square (df)		11.54 (1)***	20.35 (3)***	8.89 (2)**		1.43 (1)	21.97 (3)***	0.92 (2)
θ (variance of unobserved heterogeneity)	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Log-likelihood ratio test of $\theta = 0$, $\chi^2(1)$	0.28	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes. Standard errors in brackets. Negative coefficient = lower failure rate.
*Significant at 10%. **Significant at 5%. ***Significant at 1%. One-tailed tests for hypotheses; two-tailed tests for control variables.
Assuming gamma distribution of shared frailty with variance θ.

unobserved heterogeneity among suppliers did not affect exit rates. Thus, unobserved supplier-specific capabilities are not an alternative explanation for our results.

Testing our hypotheses required comparing the effect of the covariates on the survival of the suppliers of low- and high-modularity components. We begin by discussing the results separately for each type of supplier. We then report the results of our explicit tests for differences in the estimated coefficients across supplier types. For conciseness, we present only the results for maximum duration in the main text. Results for average duration, available from the authors, are substantively equivalent, except as noted below.

Models 1a to 1d in Table 2 present the results for the population of carburetor suppliers, which produce a low-modularity component. Model 1a contains the control variables: supplier age periods, the unknown founding date indicator, supplier size, aggregate customer production, competitor density, and national auto production. The piecewise analysis with three age periods in Model 1a is a statistically significant improvement over a model holding the rate constant. Models 1b, 1c, and 1d add relationship duration, autonomy, and customer status in turn. The addition of each factor significantly improves the fit of the model. The results are generally stable across models.

Turning to the full Model (1d), we find that in a model accounting for other aspects of a supplier's relationships, maximum relationship duration does not significantly improve supplier survival ($p = 0.13$, one-tailed test). Potential autonomy is also far from significant ($p = 0.36$, one-tailed). Lastly, having a customer of either medium or high status dramatically lowers the failure rate for carburetor suppliers, relative to having only low-status customers (ps $= 0.012$ and 0.029, respectively, one-tailed). The effects of medium- and high-status customers are statistically indistinguishable, suggesting that it was not necessary to have GM, Ford, or Chrysler as a customer to receive an imprimatur of quality. Instead, selling to Hudson, Nash, or the other major independents sufficed.

Results for the other aspects of autonomy are theoretically consistent. Failure rates for carburetor suppliers decline with current autonomy ($p = 0.004$, two-tailed). Thus, in the case of selling low-modularity components, current autonomy improves supplier survival, whereas potential autonomy does not, suggesting that it is difficult to switch suppliers for low-modularity components. The impact of having a large proportion of customers that are vertically integrated into production of a supplier's component somewhat increases the likelihood of supplier failure, although significance is only marginal ($p = 0.108$, two-tailed). Buyers with experience making a component are well positioned to replace a supplier with internal production, putting them in advantageous positions for bargaining with external suppliers. In parallel with the findings for current autonomy, this result suggests that suppliers suffer when dealing with buyers that have credible internal or external options for replacing them.

We now turn to the second set of models in Table 2, which report the results for clutch suppliers, our producers of a high-modularity component. Model 2a introduces the control variables, which tend to affect the failure rate in the same direction as in the carburetor analysis, but only the unknown founding date variable is statistically significant ($p = 0.004$, two-tailed).

Looking at the fully specified model, Model 2d, we find that maximum relationship duration has no effect on supplier survival ($p = 0.46$, one-tailed). Potential autonomy has a moderately significant influence on the failure of modular suppliers ($p = 0.059$, one-tailed), which it does not for suppliers of low-modularity components. Lastly, relative to having only low-status customers, clutch suppliers gain no survival benefit from having customers of medium or high status (ps $= 0.40$ and 0.19, respectively, one-tailed). This result is consistent with our reasoning that buyers of modular components may not require external signals of quality.

Current autonomy reduces failure ($p = 0.005$, two-tailed), as it did for carburetor suppliers. The implication is that current autonomy influences the performance of all suppliers by providing a combination of current sales, immediate alternatives, and/or direct negotiation power with existing customers.

Suppliers of highly modular components do not incur a higher failure rate by selling to vertically integrated customers ($p = 0.89$, two-tailed), a finding that contrasts with the results for low-modularity components. A possible explanation is that it is relatively easy for buyers to start production of a high-modularity component because such components are self-contained. Thus, the presence or absence of internal production among a supplier's customers does not change the credibility of customers' threats to replace the supplier with internal production. In contrast, it is more difficult for a buyer to begin production of a low-modularity component, which requires both component- and systems-level knowledge. Thus, for a low-modularity component, the presence or absence of existing internal production among a supplier's buyers significantly changes the credibility of customers' threats to replace the supplier.

Although we could not test this explanation, the data were consistent with our conjecture that auto assemblers could more easily begin producing high-modularity clutches than low-modularity carburetors. Of the 200 auto assemblers that were not vertically integrated into carburetors when they entered the data, only five subsequently produced their own carburetors (2.5%) and, of these, only one did so for more than one year. By contrast, of the 155 assemblers that did not manufacture clutches when they entered the data, 15 later produced their own clutches (9.7%), doing so for an average of over three years.[5]

In sum, the results for the suppliers of both types of component are largely consistent with our arguments. In keeping with Hypothesis 2, potential autonomy helps only suppliers of high-modularity components, which can more easily switch to new buyers. In keeping with Hypothesis 3, having high-status customers helps only suppliers of low-modularity components, for which buyers value high supplier legitimacy. Duration, the subject of Hypothesis 1, is insignificant for both components in the fully specified models.

We now compare the effect of maximum tie duration, potential autonomy, and customer status across component type, explicitly testing the hypotheses. Table 3 presents the results of difference-between-means tests (Miner et al. 1990; Wonnacott and Wonnacott 1977, p. 214) for the two fully specified models, 1d and 2d. Reinforcing the results found by examining each component separately, formally testing the significance of the difference in coefficients across components provides strong support for Hypotheses 2 and 3 and more limited support for Hypothesis 1.

Supporting Hypothesis 1, we find that maximum relationship duration is greater for low-modularity

[5] At some point in our data, 13 assemblers produced carburetors internally, and 70 produced clutches.

Table 3 Difference in Covariate Effects Across Component Types

		β(carburetor) Low modularity	β(clutch) High modularity	Absolute difference between coefficients	p(difference > 0)
H1	Max. duration of cust. relationship	−0.099	−0.066	0.033	0.052
H2	Potential autonomy	−0.059	−0.243	0.184	<0.01
H3	Maximum customer status = medium	−1.868	−0.191	1.676	<0.01
H3	Maximum customer status = high	−1.815	1.148	2.964	<0.01
	Current autonomy	−1.429	−2.192	0.763	<0.01
	Prop. of vertically integrated customer	1.978	−0.086	2.063	<0.01

Note. Negative coefficient = lower failure rate. One-tail tests for hypothesized comparisons; two-tailed tests for others.

component suppliers to a statistically significant degree ($p = 0.052$, one-tailed). However, in sensitivity analysis using average rather than maximum duration, the coefficients for duration did not differ significantly ($p = 0.245$) across components. Thus, we do not interpret this difference as strong support of Hypothesis 1.

Hypotheses 2 and 3 received much stronger support. Potential autonomy has a significantly stronger effect for suppliers of highly modular components ($p < 0.001$, one-tailed), supporting Hypothesis 2. In turn, both medium and high customer status have a larger effect on suppliers of low-modularity components ($p < 0.001$ for both, one-tailed), which supports Hypothesis 3.

For other aspects of autonomy, the larger benefit of current autonomy for producers of high-modularity components ($p < 0.001$, two-tailed) suggests that a more modular component allows a supplier to gain scale economies across multiple customers. Having a large proportion of vertically integrated customers is more harmful to suppliers of low-modularity components, a finding consistent with the argument above.

We conducted several sensitivity analyses. Investigation of alternative measures of relationship duration and customer status showed no significant impact of nonmonotonic maximum relationship duration (maximum duration squared), a Herfindahl index of the concentration of relationship durations, minimum customer status, or mean customer status in either the carburetor or clutch results. The results did not change when we dropped the density variable to check whether an arithmetic relationship between density and autonomy might affect the results. The square of the density variable was never significant. The data on clutch suppliers ended in 1937, and the data on carburetor suppliers continued until 1942. The reported results reflect use of the full data set. When we reestimated the carburetor supplier dissolution models using only data for the period until 1937, the only substantive change was that the effect of the proportion of vertically integrated customers on carburetor supplier dissolution was no longer significant, although it remained positive. Lastly, we found similar results when we replaced the gamma distribution for shared frailty with an inverse Gaussian distribution.

Discussion

This study shows that key aspects of customer relationships influence suppliers of low- and high-modularity components differently.

Consequences of Modularity

We contribute directly to the growing literature on modularity in two ways. First, we extend research on modularity's effects on buyers, which have been the focus of the modularity literature, to suppliers. Second, we refine understanding of modularity's impact on interfirm relationships. We found that suppliers of high-modularity components benefited more from potential autonomy, and suppliers of low-modularity components benefited more from ties to high-status customers. In addition, the results for customer status pointed to a less prominent feature of modularity. For a modular component, potential buyers do not value the signal generated by a supplier selling to a prominent customer. This suggests that modularity diminishes ambiguity about how well a component will perform once integrated into an end product, so that the buyer is able to evaluate the component in isolation without having to consider a web of interactions with other components.

We suggest two possible explanations for the lack of evidence for a positive effect of either maximum or average relationship duration in the full models for both components. First, the absence of evidence might be an industry-specific finding, if neither component studied here posed an extreme enough engineering challenge to reward extended relationships.

However, contemporary engineering literature and the significant results for the other variables suggest that this is not the case. A more intriguing explanation is that, just as the advantages of long-term relationships are greater for low-modularity components than for high-modularity ones, the disadvantages may also be greater for low-modularity components.

In a long-term supply relationship for a low-modularity component, the relationship-specific routines and technological knowledge become even more specialized and more weakly related to developments in an overall industry, which may be progressing more quickly or along different technological trajectories (Uzzi 1997). Performance suffers, yet the specialization discourages termination of the relationship (Gargiulo and Benassi 2000). The generality of the routines and knowledge required for high-modularity components reduces this problem. Our data do not allow us to confirm or reject these explanations unambiguously, but we hope future studies will examine further the balance of benefits and constraints that long-term relationships generate.

Our results also speak to the interfirm relationship literature by pointing to a contingency common to all three supplier relationship characteristics studied here. The benefits and constraints of a firm's relationships derive in large part from their needs (see Ahuja 2000 for similar conclusions regarding the effect of structural holes in collaboration networks on innovation). Relationships that require considerable trust and/or extensive interfirm routines produce both greater benefits and greater constraints than less intense relationships. Furthermore, relationship structure is more important for buyer–supplier connections that require high trust and extensive coordination.

It is worth considering how our results might have differed if we had examined suppliers' financial performance rather than their survival. We speculate that the survival benefits provided by affiliation with a high-status customer may come at the cost of lower profit margins. High-status customers may be in a position to strip rents from their suppliers (see, e.g., Caves and Uekusa 1976). However, this buyer ability has limits—although they can deflate supplier profitability, it is not in buyers' interests to do so to the degree that their suppliers fail. Moreover, autonomy will be particularly important here. We expect autonomy to improve profitability because suppliers with autonomy are better positioned to reject attempts to extract rents. This prediction might well apply to both low- and high-modularity components. We expect that long-term ties will contribute to a supplier's financial performance, as suppliers will capture some part of the value generated and benefit from the reluctance of their buyers to terminate relationships. Further research examining financial performance would have managerial and theoretical interest.

Managerial Implications

Our findings suggest that suppliers will find the value of their customer relationships changing in a world of increasing modularity. The reputation boost that selling to prominent customers once offered suppliers will fade as customers are better able to directly evaluate how well the suppliers' more modular components meet their needs. Nonetheless, suppliers can also benefit from these changes. A series of short-term relationships with different customers may become a viable strategy, giving suppliers flexibility in seeking out customers. A start-up firm is more able to succeed by virtue of the quality of its product, even before it gains the legitimacy that comes from sales to a large company. This is a significant benefit because new firms often lack the capacity or contacts to win orders from industry leaders.

This work also informs trends in the evolution of supplier relationships (Schilling and Steensma 2001, Vickery et al. 1999, Achrol 1997). When ambiguity about quality is high, firms tend to trade only with firms of similar status (Podolny 1994). Because high modularity reduces ambiguity about quality, trading between firms of different statuses should become more common as modularity increases. Knowledgeable buyers and suppliers will continue to avoid dependence on a small number of trading partners; firms with few partners will seek to increase the number of their partners.

Limitations and Extensions

Our study shares the limitations of other single-industry studies, although we found no obvious idiosyncrasies that would strongly limit generalization to other settings. Our empirical tests covered a dynamic period of the industry cycle in which there was substantial entry and exit of suppliers. We believe that the same influences will apply during more stable periods, but they may be less pronounced if other factors such as economies of scale contribute to supplier longevity. Examination of this issue would be informative.

Other extensions are possible. One could assess whether the impact of modularity is greater during periods of beneficial or adverse industry conditions. Modularity may have the greatest impact during downturns in an industry, when adaptation opportunities are particularly valuable and constraints are particularly binding. We believe that pursuing this comparison will be fruitful for continuing work.

In studying the impact of modularity on suppliers, we address a lacuna in the growing literature on modularity, which has emphasized buyers. Modularity is neither unconditionally advantageous nor unconditionally disadvantageous for suppliers; instead, increasing modularity requires changing strategies in the relationships that suppliers form and maintain. More generally, we show the connection between the coordination requirements of a supplier's relationships and the benefits and constraints that the relationships create.

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References

Achrol, R. S. 1997. Changes in the theory of interorganizational relations in marketing: Towards a network paradigm. *J. Acad. Marketing Sci.* **25**(Spring) 56–71.

Ahuja, G. 2000. Collaboration networks, structural holes, and innovation: A longitudinal study. *Admin. Sci. Quart.* **45**(3) 425–445.

Asanuma, B. 1989. Manufacturer-supplier relationships in Japan and the concept of relation-specific skill. *J. Japanese Internat. Econom.* **3**(1) 1–30.

Automotive News: The 100-Year Almanac and 1996 Market Data Book. 1996. American Automobile Centennial, 1896–1996; V. 1, April 24, 1996. Automotive News, Detroit, MI.

Automobile Quarterly. 1971. *The American Car Since 1775: The Most Complete Survey of the American Automobile Ever Published*. L. S. Bailey, New York.

Baker, W. E. 1990. Market networks and corporate behavior. *Amer. J. Sociol.* **96**(3) 589–625.

Baker, W. E., R. R. Faulkner, G. A. Fisher. 1998. Hazards of the market: The continuity and dissolution of interorganizational market relationships. *Amer. Sociol. Rev.* **63**(2) 147–177.

Baldwin, C. Y., K. B. Clark. 2000. *Design Rules. Vol. 1: The Power of Modularity*. MIT Press, Cambridge, MA.

Barnett, W. P., M. T. Hansen. 1996. The Red Queen in organizational evolution. *Strategic Management J.* **17**(Summer) 139–157.

Burt, R. S. 1980. Autonomy in a social topology. *Amer. J. Sociology* **85**(4) 892–925.

Burt, R. S. 1992. *Structural Holes: The Social Structure of Competition*. Harvard University Press, Cambridge, MA.

Caves, R. E., M. Uekusa. 1976. *Industrial Organization in Japan*. The Brookings Institution, Washington, D.C.

Clark, K. B., T. Fujimoto. 1991. *Product Development Performance*. Harvard Business School Press, Boston, MA.

Cook, K. S. 1977. Exchange and power in networks of interorganizational relations. *Sociol. Quart.* **18** 62–82.

Cook, K. S., R. M. Emerson. 1978. Power, equity and commitment in exchange networks. *Amer. Sociol. Rev.* **43**(5) 721–739.

Dussauge, P., B. Garrette, W. Mitchell. 2000. Learning from competing partners: Outcomes and durations of scale and link alliances in Europe, North America, and Asia. *Strategic Management J.* **21**(2) 99–126.

Dyer, J. 1996a. Does governance matter? Keiretsu alliances and asset specificity as sources of Japanese competitive advantage. *Organ. Sci.* **7**(6) 649–666.

Dyer, J. 1996b. Specialized supplier networks as a source of competitive advantage: Evidence from the auto industry. *Strategic Management J.* **17**(4) 271–291.

Dyke, A. L. 1923. *Dyke's Automobile and Gasoline Engine Encyclopedia: The Elementary Principles, Construction, Operation and Repair of Automobiles, Gasoline Engines and Automobile Electric Systems, Including Trucks, Tractors, and Motorcycles, Simple, Thorough and Practical*. The Goodheart-Willcox Company Inc., Chicago, IL.

Eccles, R. G. 1981. The quasifirm in the construction industry. *J. Econom. Behav. Organ.* **2** 335–357.

Emerson, R. M. 1962. Power-dependence relations. *Amer. Sociol. Rev.* **27** 31–41.

Ethiraj, Sendil K., Daniel Levinthal. 2004. Modularity and innovation in complex systems. *Management Sci.* **50**(2) 159–173.

Galunic, D. C., K. M. Eisenhardt. 2001. Architectural innovation and modular corporate forms. *Acad. Management J.* **44**(6) 1229–1249.

Gargiulo, M., M. Benassi. 2000. Trapped in your own net? Network cohesion structural holes, and the adaptation of social capital. *Organ. Sci.* **11**(2) 183–196.

Garud, R., A. Kumaraswamy. 1995. Technological and organizational designs for realizing economies of substitution. *Strategic Management J.* **16**(Special issue) 93–109.

Gulati, R. 1995. Does familiarity breed trust—The implications of repeated ties for contractual choice in alliances. *Acad. Management J.* **38**(1) 85–112.

Gunnell, J. 1982. *Standard Catalog of American Cars, 1946–1975*. Krause Publications, Iola, WI.

Guo, G. 1993. Event-history analysis of left-truncated data. *Sociol. Methodology* **23** 217–242.

Gutierrez, R. G. 2002. Parametric frailty and shared frailty survival models. *Stata J.* **2**(1) 22–44.

Hannan, M. T. 1998. Rethinking age dependence in organizational mortality: Logical formalizations. *Amer. J. Sociol.* **104**(1) 126–164.

Hoetker, G. 2006. Do modular products lead to modular organizations? *Strategic Management J.* **27**(6) 501–518.

Kennedy, E. D. 1941. *The Automobile Industry; The Coming of Age of Capitalism's Favorite Child*. Reynal & Hitchcock, New York.

Kimes, B. R. 1989. *Standard Catalog of American Cars, 1805–1942*, 2nd ed. Krause Publications, Iola, WI.

Langlois, R. N., P. L. Robertson. 1992. Networks and innovation in a modular system: Lessons from the microcomputer and stereo component industries. *Res. Policy* **21**(4) 297–313.

Levinthal, D. A., M. Fichman. 1988. Dynamics of interorganizational attachments—Auditor-client relationships. *Admin. Sci. Quart.* **33**(3) 345–369.

Lucke, Charles Edward, Friederich Otto Willhöfft. 1917. *Carburetor Design: A Preliminary Study of the State of the Art* (*NACA Report 11*). National Advisory Committee for Aeronautics, Washington, D.C.

Mandel, L., Harrah's Automobile Collection. 1982. *American Cars: From Harrah's Automobile Collection*. Stewart Tabori & Chang, New York.

Martin, X., A. Swaminathan, W. Mitchell. 1998. Organizational evolution in the interorganizational environment: Incentives and constraints on international expansion strategy. *Admin. Sci. Quart.* **43**(3) 566–601.

Mikkola, Juliana Hsuan. 2003. Modularity, component outsourcing, and inter-firm learning. *R&D Management* **33**(4) 439.

Miner, A. S., T. L. Amburgey, T. M. Stearns. 1990. Interorganizational linkages and population-dynamics: Buffering and transformational shields. *Admin. Sci. Quart.* **35**(4) 689–713.

Mitchell, W., K. Singh. 1996. Precarious collaboration: Business survival after partners shut down or form new partnerships. *Strategic Management J.* **17**(3) 95–115.

Monteverde, K., D. J. Teece. 1982. Supplier switching costs and vertical integration in the automobile industry. *Bell J. Econom.* **13**(1) 206–213.

Nelson, P. 1970. Information and consumer behavior. *J. Political Econom.* **78** 311–329.

Newcomb, T. P., R. T. Spurr. 1989. *A Technical History of the Motor Car*. A. Hilger, Bristol, UK.

Page, V. W. 1918. *The Modern Gasoline Automobile: Its Design, Construction, Operation and Maintenance*. Norman W. Henley, New York.

Peterson, T., P. V. Marsden. 1991. Time-aggregation bias in continuous-time hazard-rate models. *Sociol. Methodology* **21** 263–290.

Pfeffer, J., G. R. Salancik. 1978. *The External Control of Organizations*. Harper & Row, New York.

Podolny, J. M. 1993. A status-based model of market competition. *Amer. J. Sociol.* **98**(4) 829–872.

Podolny, J. M. 1994. Market uncertainty and the social character of economic exchange. *Admin. Sci. Quart.* **39**(3) 458–483.

Powell, W. W., K. W. Koput, L. Smith-Doerr. 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Admin. Sci. Quart.* **41**(1) 116–145.

Ring, P. S., A. H. Van de Ven. 1994. Developmental processes of cooperative interorganizational relationships. *Acad. Management Rev.* **19** 90–118.

Rockart, Scott. 2003. Experience quality and competition. Working paper, Duke University, Durham, NC.

Sanchez, R., J. T. Mahoney. 1996. Modularity, flexibility, and knowledge management in product and organization design. *Strategic Management J.* **17** 63–76.

Schilling, M. A. 2000. Toward a general modular systems theory and its application to interfirm product modularity. *Acad. Management Rev.* **25**(2) 312–324.

Schilling, M. A., H. K. Steensma. 2001. The use of modular organizational forms: An industry-level analysis. *Acad. Management J.* **44**(6) 1149–1168.

Simon, H. A. 1969. *The Sciences of the Artificial*. MIT Press, Cambridge, MA.

Singh, K., W. Mitchell. 1996. Survival of businesses using collaborative relationships to commercialize complex goods. *Strategic Management J.* **17**(3) 169–196.

Smith, P. H. 1968. *Wheels Within Wheels; A Short History of American Motor Manufacturing*. Funk & Wagnalls, New York.

Spence, M. 1973. Job market signaling. *Quart. J. Econom.* **87** 355–374.

Stuart, T. E. 1998. Network positions and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry. *Admin. Sci. Quart.* **43**(3) 668–698.

Stuart, T. E., H. Hoang, R. C. Hybels. 1999. Interorganizational endorsements and the performance of entrepreneurial ventures. *Admin. Sci. Quart.* **44**(2) 315–349.

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

United States Bureau of the Census. 1989. *Historical Statistics of the United States, Colonial Times to 1970*. Kraus International Publications, White Plains, NY.

Uzzi, B. 1997. Social structure and competition in interfirm networks: The paradox of embeddedness. *Admin. Sci. Quart.* **42**(1) 35–67.

Vickery, S., R. Calantone, C. Droge. 1999. Supply chain flexibility: An empirical study. *J. Supply Chain Management* **35**(3) 16–24.

Walker, G., B. Kogut, W. J. Shan. 1997. Social capital, structural holes and the formation of an industry network. *Organ. Sci.* **8**(2) 109–125.

Williamson, O. E. 1985. *The Economic Institutions of Capitalism*. Free Press, New York.

Williamson, O. E. 1993. Calculativeness, trust, and economic organization. *J. Law Econom.* **36**(1) 453–486.

Wonnacott, T. H., R. J. Wonnacott. 1977. *Introductory Statistics for Business and Economics*, 2nd ed. John Wiley and Sons, New York.

Zenger, T. R., W. S. Hesterly. 1997. The disaggregation of corporations: Selective intervention, high-powered incentives, and molecular units. *Organ. Sci.* **8**(3) 209–222.