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Research Paper

Firm Partial Modularity and Performance in the Electronic Manufacturing Services Industry

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ABSTRACT Firms continue to develop new ways to decentralize non-core activities to outside parties. Scholars have approached this issue with modularity theory, suggesting a continuum of arrangements ranging from hierarchy to market. Hierarchy relies on fiat, while partially modular forms, those forms between hierarchy and market, require greater coordination, communication and relationships between firms than do fully modular (or market) forms. While modularity theory identifies this continuum, the associated empirical literature tends to dichotomize modularity: firms are either modular or they are not. Nor does the empirical literature examine the performance outcomes of modular arrangements within this continuum. By examining firms that vary between full integration and partial modularity with a continuous modularity measure, this paper empirically examines the performance outcomes associated with a range of modularity levels. We derive this measure from a peculiar inventory option available within the electronic manufacturing services (EMS) industry. Our data include observations on 260 firms over five years. We find that more firms rely on partially modular arrangements, the lower their performance. We suggest explanations for this result, and areas of future research meant to pursue it.

KEY WORDS: Modularity, vertical integration, contract manufacturing, inventory

The range of options between hierarchies and markets, supported by varying levels of modularity, has become a popular topic in the strategic management literature (e.g. Sanchez and Mahoney, 1996; Baldwin and Clark, 2000; Brusoni and Prencipe, 2001; Sturgeon, 2002; Mikkola, 2006). Modularity describes "the degree to which a system's components can be separated and recombined" (Schilling, 2000: 213) and "exponentially increases the number of possible configurations achievable from a given set of inputs,

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greatly increasing the flexibility of a system" (Schilling, 2000: 213). Modularity allows modular partners to assume responsibility for tasks outside the core competency of the focal firm (Staudenmeyer *et al.*, 2005).

Modularity underlies a continuum ranging from the vertical integration of capabilities to depending entirely on the external market for those capabilities (Garud and Kumaraswamy, 1995). However, the dichotomous distinction between fully vertically integrated and fully modularized often employed in this research (Schilling and Steensma, 2002) belies the complexity inherent in organization. Rather than choosing vertical integration, with its reliance on hierarchical control, or a fully modularized arrangement, with its focus on contracts and minimal communication, some organizations occupy an intermediate realm. In this middle space, partners are not part of the same firm, but nor is communication as formalized and minimal as in full modularity. In addition, while the literature on modularity generally assumes or suggests a positive relationship between modularity and firm performance, empirical examinations of this relationship remain limited (for an exception based on perceptual data, see Worren *et al.*, 2002). Instead, researchers have empirically examined, for example, the industry-level determinants of modularization (Schilling and Steensma, 2001; Mikkola, 2006), the implications of modularity for product development (Staudenmeyer *et al.*, 2005), the influence of modularity on innovation and imitation behavior (Pil and Cohen, 2006), and the effects of modularity on reconfiguration strategies (Karim, 2006). Other empirical work documents, however, that even within the same industry, firms display heterogeneity in the extent of their modularization (Worren *et al.*, 2002; Hoetker, 2006). This within-industry variation begs both for the identification of firm-level determinants of modularization and the firm-level performance implications of modularity choices. We provide evidence on the latter here, explicitly recognizing modularity as a continuum through an objective measure that ranges from vertical integration through various levels of partial modularity.

We first suggest rationales for why more modular firms might be expected to outperform less modular firms (as the literature generally assumes or suggests). We go on to discuss why this relationship might also be non-monotonic or alternatively, why more modular firms might be expected to perform worse than less modular firms. We generate hypotheses on the basis of these rationales. We then examine our hypotheses in the context of the electronic manufacturing services (EMS) industry, an industry particularly useful for examining modular structures (Sturgeon, 2002), and the source of our continuous measure of modularity. Our results suggest that the more firms rely on partially modular arrangements, the lower their performance. We conclude with a discussion of the implications of this finding.

Modularity and Firm Performance

For this study, partial modularity, as with traditional modularity definitions, refers to the use of an external party to complete an important aspect of the value chain. In this study we investigate the use of arrangements that are not completely modular, and thus may be associated with considerable communication and coordination costs for both parties. The use of partial modularity, while potentially creating costs, however, may also be creating efficiencies. For illustration, we use the relationship between an architect and a construction firm. Many times, the architect and the builder are completely separate firms who must come together to solve a complex problem, one that will often necessitate revision and frequent communication. Neither firm can accomplish their task independently nor can a formalized routine solve the

inherent complexity of their communication needs. Traditional approaches and definitions of modularity do not well accommodate this relationship, as most studies tend to dichotomize between vertical integration and fully modular systems. The relationship between the architect and the construction firm is clearly not a hierarchy nor fully modular; it exists in between conceptions of hierarchy and modularity. We call these types of arrangements "partial modularity". Partially modular arrangements do not rely on fiat, nor can they rely simply on the formal and clear language of markets and instead rely on coordination (formal and informal) mechanisms between firms.

Recently, Makadok and Coff (2009) discussed a similar concept, though they refer to partial modularity as "quasi-integration". In their model, as in ours, a partially modular (or quasi-integrated) arrangement is characterized by a long-term relationship between the supplier and buyer and strong incentives for cooperation, but the arrangement is not well governed by a contract, as would be required in a traditional modular/market type arrangement. They highlight the tight integration between Toyota Motors and its supply chain as an example, where Toyota knows detailed information about their suppliers' costs and uses that information to facilitate exchange. The exchange between the firms functions at a middle point between a purely market exchange and that of a fully integrated firm. Toyota does not use its information to extract unusual rents from its supplier, instead it uses it facilitate trust and efficiency. In our analysis, firms vary in the extent to which they own the individual components of the value chain, thus we use the term partial modularity to differentiate from Makadok and Coff's conception where each firm is entirely separate. In our setting, we observe firms trying to run their business like Toyota as well as firms who are trying to operate as fully integrated suppliers, along with significant variance in between. We investigate below whether or not the increasing use of partially modular relationships across partners is good for the focal firm's performance.

Positive relationship

The predominant view of firm modularity focuses on the use of coordinating mechanisms, such as standard product architecture and other industry norms to coordinate activities between firms (e.g. Schilling, 2000; Schilling and Steensma, 2001). These systems improve coordination and create a common language for firms within the industry and enable modular organizational forms. Modularity in turn allows modular partners to specialize in their respective core competencies (Staudenmeyer *et al.*, 2005). More specialization means that the firm must rely on other firms for key inputs. In short, the industry becomes more and more networked—a system that encourages higher quality (Hill, 1990; Hill *et al.*, 1992) and more commitment from other firms in the network (Uzzi, 1997). The use of modularity and partial modularity as structures increase firms' ability to tap into this network, reducing the cost of doing business and increasing the likelihood of new business in the future. The use of modular systems should improve the firm's ability to extract the most value from its resources while reducing administrative costs and thus increase its performance. Each firm can specialize and develop in a tightly defined competency. If the industry can generate and sustain its network using standardized procedures and communication, both focal and partner firms will be able to use these systems to improve their individual performance (Worren *et al.*, 2002).

Where firms cannot *fully* outsource a particular input because of a lack of suitable outsourcing partners or the absence of standard product architecture and other industry

norms, many firms will utilize only *partially* modular structures. Thus, this view suggests that partial modularity, although perhaps not as effective as complete modularity, will still provide positive benefits to firms.

Hypothesis 1: Partial modularity is positively associated with firm performance.

However, while its focus on coordinating mechanisms leads much of modularity theory—with its equilibrium-based perspective—to suggest a positive causal relationship between modular organization (partial or otherwise) and performance, other considerations suggest that the use of such organizational structures does not positively influence performance, but rather that this relationship should be non-monotonic or negative. We first turn to non-monotonic, and later to negative, relationships.

Non-monotonic/curvilinear relationship

The use of modularity is the choice between specialization and control (Schilling and Steensma, 2001). Firms that are entirely modular are focused exclusively on one particular aspect of their value chain. By design, however, this leads to a loss of capacity in aspects of the firm's business that are deemed non-central. As a firm becomes more specialized and more dependent on its modular partners, it has less control over the outsourced aspects of its value chain. For instance, a manufacturing firm that employs an outside partner to manage its distribution becomes completely dependent on the modular partner. However, if the distribution breaks down the firm remains accountable to customers for an activity that is not only outside its control but also outside its realm of expertise to monitor.

Similarly, the more a firm integrates the components of its production, the more difficult it will be to develop a specialized learning base in any one particular component of the value chain (Jacobides and Winter, 2005). Carrying forward the manufacturing firm example, the firm that manages its own distribution, in contrast to firms who allow modular partners to do so, could spend too much energy generating value in distribution and not enough on its core capabilities. Fundamentally, the firm is concerned with both learning and control (Argyres, 1996). The use of a particular structure does not reduce the need for routines to deal with the necessities of both producing and transacting. It is that special firm, which is able to balance these needs and gather as many capabilities as possible, which will sustain a competitive advantage from the use of modular structures. These firms will know enough about their value chain to operate efficiently for their customer while developing enough knowledge to selectively outsource particular functions. Outsourcing some functions while retaining others enables the firms to generate a superior capability base and generates effective knowledge structures without excessive administrative costs (Parmigiani, 2007). Firms most concerned with doing both activities well will learn more and gather more from the market than firms which are too closely aligned to a single structural choice.

Finally, research into the application of modularity theory suggests boundaries to its application. Galvin and Morkel (2001) suggest that modular firms require a larger social network to operate. As the firm's social capital increases, the demands on managers' attention also increase in order to maintain this social capital. While the social capital forms the foundation for market responsiveness, the difficulty of sustaining a high interconnectedness with peer firms begins to distract managers from value-creating activities. Takeishi (2002) suggests that the difficulty inherent in solving particularly complex problems between

a supplier and a partner firm requires a level of integration that operating completely independently might not provide. As the complexity of the operation increases, firms may begin to receive diminishing marginal returns from increased modularity. The difficulty of monitoring disparate modular partners, maintaining adequate knowledge stocks within the organization and maintaining the social capital which modular organization requires will lead to an inverted U-shaped effect. As firms begin to employ modular and partially modular organization, they will begin to see an increase in performance from the benefits which modular organization bestows. However, as the fiscal, human and social costs of partial modularity increase, increasing use of these arrangements will show a detrimental effect on performance.

Hypothesis 2: Partial modularity is positively but non-monotonically associated with firm performance.

Negative

A less well-explored path regarding modular organization suggests how modularity might lead to poor performance and comes from the network literature. Within that literature, some authors have emphasized the potentially negative influence of organizational ties. Powell (1990), most prominently, points out that networks can lead to a lack of innovation because it is difficult to create the intra-process connections necessary for innovation (Fleming and Sorenson, 2001). Danneels (2003) finds that as firms become too dependent on their clients, their performance suffers as they miss outside opportunities. As firms within the network depend on one another for information concerning new technologies, they begin to lose the ability to incorporate information from other sources to create new approaches to problems. We suggest in turn that the more partially modular a firm becomes, and the more it draws on relationships with outside firms to organize itself, the less effective it will become. Instead of a clear chain of responsibility born of internal organization, the firm must now concern itself with organizing across different firms and integrating its operations with the demands of its modular partners (Hoetker, 2006). This administrative and communication burden leads to a higher cost of doing business and while the firm may become more flexible in the marketplace, its ability to be efficient or effective falters.

Ernst (2005) echoes a similar sentiment when he argues that modularity theory is too widely applied in practice. In his review of the microchip design industry, an industry where firms routinely outsource key components of production, he found that firms seemed to be migrating towards a more integrated organizational structure and away from modular organizational designs. The complexity introduced by product modularity was forcing firms to constrict their organizational design and centralize authority, making them less organizationally modular. As the costs of modularity become clear, firms who are not fully modular will bear the same costs. Ultimately, a partially modular organizational form does not gain the efficiency benefits from modularity or the learning benefits from vertical integration. We suggest that when firms engage in the strategic outsourcing of functions that are not easily divisible from the rest of the value chain, such as the purchasing role in Figure 1, they are introducing communication costs into the organization that will hinder performance. Thus, we suggest the last of our competing hypotheses.

Hypothesis 3: Partial modularity is negatively associated with firm performance.

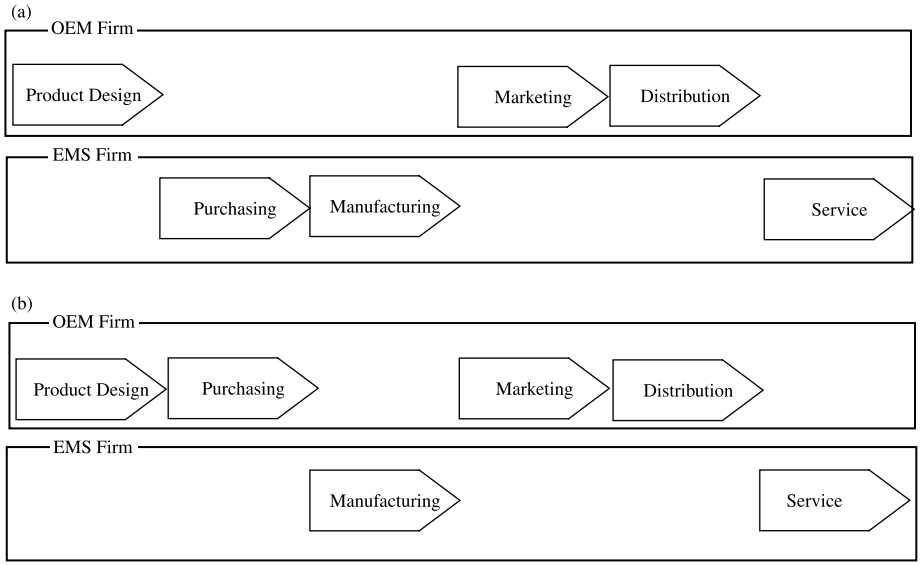

Figure 1. Inventory arrangements in EMS firms: (a) traditional inventory arrangement (turnkey); (b) modular inventory arrangement (consignment)

We investigated our hypotheses in the electronic manufacturing services (EMS) industry. This industry offers both considerable heterogeneity in the use of a particular modular structure, consignment inventory, as well as a clear measure of firm performance: efficiency. We discuss why consignment inventory occupies a middle ground between traditional conceptions of hierarchies and markets, and how this particular modular arrangement can thus inform modularity theory. Below, we will explore the complexity of this industry to motivate our empirical model and discussion.

The EMS Industry[1]

The EMS industry began in the 1960s, as several firms established themselves to meet the developing outsourcing needs of original equipment manufacturers (OEMs). The first major EMS firm, Sparton, for example, began operations in 1961 as a producer of military control assemblies and spacecraft equipment for the aerospace industry. SCI (now Sanmina-SCI, one of the five major EMS firms in 2002[2]), began operations around the same time—opening shop as a producer of electronic assemblies for the US Government (www.sci.com). EMS firms were originally often hired to either absorb unanticipated demand that the OEM's internal production capacity could not support or produce products that were too specialized for OEMs to manufacture internally. As a result, EMS firms were

[1] The authors would like to thank employees at Jabil Circuit, ASCOM and Solectron for their helpful comments and guidance in developing this summary.

[2] The six largest EMS firms as of September 2002, in order of revenue, were Flextronics, Solectron, Sanmina-SCI, Celestica, Foxconn and Jabil Circuit (Lehman Brothers, 2002). Flextronics acquired Solectron in 2007.

subject to extreme market volatility and frequent bankruptcy. While originally exclusive providers to one or two customers, over time EMS firms began to offer services to an increasing number of clients, allowing them to take advantage of economies of scale. During the early 1980s, OEMs began to take greater advantage of the economies associated with outsourcing larger portions of their manufacturing needs to EMS firms, and the EMS industry became somewhat more stable. Today, EMS firms have increasingly become the sole producers of the OEMs' finished products, while the OEMs remove themselves from manufacturing entirely. In addition to economies of scale in manufacturing, OEMs realize other benefits from such outsourcing: a smaller capital base related to factories or warehouses, and the additional flexibility of manufacturing closer to customers worldwide than OEMs could afford alone. In an effort to make products more manufacturable, EMS firms are additionally taking over more of the design functions that OEMs once controlled. Under these arrangements, product design engineers at the OEM specify the requirements of a particular electrical device, and the EMS design team designs an easily assembled component that meets the customer's functional requirements. Understanding the electrical component production process is critical to keeping the cost of production down, so the EMS firm is better equipped than the OEM to design individual assemblies. There are two main technologies in this industry, and they are fundamentally different in their impact on the firm.

The first and more recent technology is surface mount technology (SMT). SMT components are made of very small components placed on a circuit board. The parts are secured in place with a paste-like compound that turns into a metallic connection when heated. The placement of the components on the board is extremely precise and the entire process is completely automated. The only laborers required to construct these kinds of components are the test personnel and an employee to monitor the process during operation. This technology requires high levels of capital, and the relevant machines must be utilized a considerable portion of the day to ensure a return on a firm's investment. The SMT technology is often used to generate the control components that are required by the more robust boards—built with the other major technology, through-hole assembly.

The second technology, through-hole, generates a product that looks very much like a stereotypical circuit board. These boards have large components that protrude from their surface. Pins from the component run through the circuit board and extend beyond the bottom of the silicon board. Resistors, connectors, capacitors and transformers are all placed on these boards, and they generally must be placed by hand due to their size and shape. Laborers on an assembly line must insert the parts. The components that go into this technology must be prepared before the laborer can insert them. The complexity of the insertion process means that the factory must employ laborers to alter the parts when they come from the suppliers, employees to insert the parts on the final assembly, and technicians to check and finish the final assembly once it leaves the assembly line. This is a very labor-intensive process and factories will generally be placed in areas that offer inexpensive labor. The capital requirements of a through-hole process are generally lower than those of SMT processes. However, in addition to the costs of manual assembly, through-hole components require extensive touch-up and error checking once they have left the assembly area, a requirement that further increases labor costs. These extensive labor requirements make through-hole manufacturing the more inefficient production method, negatively affecting operational efficiency.

Given the focus of OEMs on cost, the key performance determinant for EMS firms is operating efficiency. EMS firms that cannot compete on price are not viable competitors within the industry because there are not many effective strategies for EMS firms to differentiate themselves. Because there are few opportunities for differentiation, firms often seek out ways to increase their service offering and their revenue. Larger EMS firms have developed a global footprint to meet the needs of their clients, some have entered into distribution agreements, and EMS firms are increasingly moving up the value chain into product design.

Because OEMs are entirely dependent on the quality of the EMS manufacturing, these two firms are absolutely dependent on one another. The OEM cannot determine the quality of the EMS's manufacturing effort because electronic components are extremely susceptible to electro-static discharge. Any contact with a charged surface can be extremely damaging to an electronic component. Generally, any failure of an electronic component within two years of normal operation is a result of poor manufacturing quality. As a result, poor manufacturing quality by the EMS can mean a poor reflection on the OEM, even after several years.

In short, OEMs have a strong incentive to maintain a good relationship with their EMS suppliers. Similarly, if the OEM feels that the EMS firm is abusing its relationship it can ruin the reputation of the EMS within the industry and destroy its business—making the EMS dependent on the OEM for its reputation as well as its business. This customer–supplier dyad is incredibly strong and important for the success of both firms.

One outcome of this dyad is the way that the two firms organize their inventory management. EMS firms tend not to make their own raw components. Instead, they either buy them themselves or allow their customers (OEMs) to buy them. Inventory controlled by the EMS is referred to as "turnkey" inventory, while inventory controlled by the customer is called "consignment" inventory. Consignment inventory lowers the cost of the inventory for the EMS, while the OEM can then ensure the quality of the components entering its product. Because high quality/low costs are the key determinants of success for EMS firms, being given their inventory might be in their best interest as well as in the OEM's.

EMS firms who participate in consignment inventory agreements are dependent on the OEM for their productivity and success. If the OEM fails in its inventory control for the EMS, the EMS firm will be forced to engage in costly production line stoppages and plant closures, costs which are pushed back to the OEM. In short, consignment inventory forces the two firms to be more dependent on one another than the existing coupling resulting from the use of contract manufacturer. Figure 1 depicts the two potential arrangements we are highlighting this paper: consignment inventory and turnkey operations.

Methods

The Sample

To look at the use of modular structures and their impact on firm efficiency, we chose the five-year period prior to 2000 because the EMS industry experienced considerable globalization after 2000, as well as a dramatic decrease in previously inflated valuations after 2001 that overshadowed all transactions past that point. Our data comes from *Electronic Buyers' News*, 1995–99. *Electronic Buyers' News* conducts a survey every year

of all contract electronic manufacturing firms in existence in the USA and Canada. The annual survey lists services in through-hole, SMTs, manufacturing-related services, distribution, quality programs, percentage of contracts where the company purchases its own inventory, employees, number of factory facilities and revenue. EMS firms have a good incentive to submit information to this survey, as this is a primary means of communication with OEM firms. However, the survey is limited to characteristics of EMS firms, and thus our analysis only examines the performance implications of consignment relationships for the EMS firms.

Because not all firms reported in every year and there was considerable entry and exit during this time period, panel data analysis is the most insightful. After removing firms who did not report all the variables of interest (in particular, firms tended not to report their revenue statistics), we had data on 252 firms over five years totaling about 513 useable observations. Supplemental analysis showed no difference between the firms who reported versus those who did not report in terms of number of employees and number of facilities.

The Model

Traditionally, these data would best be modeled using a fixed-effects regression, to control for differences between firms and over time. However, because firms in this industry were contracted for their services, there is not a considerable amount of variance within each firm over the five-year time period. For instance, if a firm is using consignment inventory with its partners in 1995, it is very likely to have the same amount of consignment inventory five years later. Because there is not a great deal of variance within firms on our independent variable (within-firm change mean $= 0$, SD $= 7$), we have chosen to look at the impact of consignment inventory between firms using a between-effect regression. This technique regresses our variables of interest on the mean for each firm. We have thus ignored the variance within each firm over time, reducing our sample to 260. Typically, the problems associated with balancing between the use of a within-firm regression (traditional fixed-effect) and the variance between firms can be solved by employing a random-effects regression. Although random-effects models can be used when there are few time periods for each panel and the individual data does not vary much over time (Wooldridge, 2002: 286), we found that our data does not support the assumptions of a random-effects model using the Breusch and Pagan test for random effects ($X^2 = 39.16$, $p < 0.01$).

Because the nature of the contracts between firms does not vary considerably within firms over time, we employ a between-effects model. However, the use of a between-effects regression technique would be ineffective if we were unable to classify the other operations for each firm that might impair its efficiency. Fixed-effect regressions would allow us to control for individual aspects of the firm, aside from our data, by removing the firm average from each panel and only examining the impact of consignment inventory or our control variables. By removing the panel aspect of our data, we are only looking at the effect that occurs when comparing one firm to another, not the change that occurs within each firm following an adjustment to one of the independent variables. Thus, the data have become cross-sectional over the five years of our data. In addition, because our efficiency variable has a strong right-hand skew, we have log-transformed the dependent variable to address this violation of normality (Box and Cox, 1964).

Dependent variable. In contrast to previous studies of the relationship between modularity and firm performance (Worren *et al*., 2002), we utilize objective rather than perceived performance data. We used an efficiency measure to assess firm performance, measured as revenue per employee. This particular measure is an industry standard for performance, and is often used in the same way as "load factor" measures in the airline industry. A firm's load factor, like its revenue per employee, is a measure of the ability of the firm to gather revenue given its capacity to do so. In the airline industry, firms improve performance by increasing the revenue per available seat miles (Miller and Chen, 1996). Similarly, revenue per employee in the EMS industry is a measure of the firm's ability to complete customer orders as efficiently as possible. By using efficiency as the measure of firm performance, we are addressing the key performance measure in this industry. Accounting figures, particularly for non-public firms, are difficult to attain. We have avoided the necessity for self-report financial performance data by using a different performance measure, one in common use within the industry.

Independent variable. We measured partial modularity in the EMS industry as the percentage of inventory (ranging from 0 to 100) that is managed externally to the firm. A zero on this measure means that the firm manages its inventory exclusively (turnkey inventory). Alternatively, a 100 on this measure means that firms are completely dependent on their modular partner for inventory acquisition (consignment inventory). A firm engaged in a higher percentage of consignment inventory entrusts more of its inventory control to its customers.

Control variables. Because we are using efficiency as our dependent variable, our study requires a considerable amount of statistical control in order to effectively isolate the influence of modularity. In addition to the method the EMS uses to control its inventory, several other characteristics might influence the firm's efficiency because they influence the complexity of the firm's operations. These characteristics include firm size, scope of service offerings, the manufacturing technology employed and their use of quality control programs.

Controlling for firm size accounts for the difficulties associated with coordinating a larger firm. We used a composite measure of firm size developed by factor scoring the size of the firm's largest manufacturing plant, the number of overseas facilities it has and the number of surface mount technology lines the firm has to generate a composite score for the firm's size. This was done to ensure a more robust representation of each firm than would have been possible with a single measure. All of these measures were correlated greater than 0.6 and they generate a factor structure with only one factor (eigenvalue of first factor = 2.1 and eigenvalue of second factor less than 0.5).

In order to further isolate the importance of inventory policy on firm performance, we needed to control for the vast differences in services that exist between firms in this industry. We measure scope in service offerings—also presumably associated with higher coordination costs—as the number of different services a firm offers, grouped by the *Electronic Buyers' Guide* broad service categorizations. To verify the industry publication's categorization of services, we asked a strategic planning manager at one of the largest six firms in the EMS industry to examine the service categories. His opinion confirmed our belief that beyond offering basic services, increasing the number of services within each category represented meeting a niche need for clients that involves higher capital investment and

training time—and thus lower efficiency. There were four broad service categories, each with more specific services identified within: design services (five types), distribution services (three types), manufacturing services (six types) and testing services (seven types). We measured the complexity of the firm's activities in each of these areas as the number of service types offered within each service category.

As we highlighted in our discussion of the industry, there are two basic manufacturing technologies: through-hole and surface mount technologies characterize this industry. These two technologies have fundamentally different capital and labor requirements and thus have considerable implications for the efficiency of the firm. To control differences between firms due to the use of either SMT or through-hole technology, we introduced a count for the firm's use of these technologies. We introduced a count of SMT technologies (nine types) and through-hole technologies (four types).

Finally, to control for possible efficiency differences associated with quality programs, we included a dummy variable that was coded "1" if the firm engaged in any quality program such as ISO certification or total quality management (TQM), etc. Quality programs, although perhaps beneficial to a firm's quality, often reduce operational efficiency by requiring large amounts of documentation and paperwork. The broad selection of different military, aerospace and medical certifications within our sample made controlling for individual quality programs between firms infeasible.

To characterize the arrangements between OEM and EMS firms as "relationships" in the relationship contracting sense, it would be best to quantitatively measure the quality of the interpersonal relationships between the two types of firms. This study was unable to do this explicitly. Given the limited nature of the firm-specific data available and the breadth of the sample, measuring and characterizing interpersonal relationships was not possible. We have tried to solve this problem in two ways. First, the independent variable of interest in our study is a good proxy for how much of the EMS's business is dependent on close cooperation with its customers. Consignment inventory necessitates more communication and integration with the OEM, as the EMS firm must now relate not only its inventory requirements whenever it needs to purchase inventory but also its waste percentages and work-in-progress levels. In addition, by controlling for size, we have tried to adjust for potential differences in firm bargaining power and their tendency to use consignment or turnkey inventory arrangements.

Secondly, our data do capture the longitudinal dynamics of these relationships over time. It stands to reason that EMS firms who are unsatisfied with their consignment arrangement will reduce or exit the relationship. Because we have longitudinal data, we have adjusted for these changes by using the average consignment inventory level over a five-year window. In this way, we have controlled for the quality of the relationship by observing the behavior of the firms involved in them. A firm unhappy with their modular agreement will decrease their level of consignment inventory over time, and this will be reflected in our data.

To ensure that our results were robust to using indicator variables instead of count measures, we also ran the models presented below using indicator variables rather than count variables. These models had essentially the same implication for our independent variable, but these measures of operational complexity became very difficult to interpret as we were left with several indicator variables for what is now represented by a limited number of count variables. As a result, we present the models employing count measures.

Results

Summary results and correlations are displayed in Table 1. Table 2 displays the estimates for the regression equation. The standard errors of our regression coefficients are displayed in parentheses below the coefficient estimates. We report the *R*-squared value for the regression underneath the omnibus significance test.

Our results indicate that the decision to use consignment inventory has a significant and negative effect on EMS firm efficiency. After controlling for the size of the firm, the kind of services the firm offers and whether or not it utilizes quality programs, the more that an EMS relies on the OEM for its inventory, the less efficient the EMS becomes ($p < 0.05$). This result is contrary to Hypothesis 1 but supports Hypothesis 3. In addition, the inverted U-shaped effect suggested in Hypothesis 2 is not supported by its test, the squared term in Model 3 ($p = 0.891$). The use of consignment inventory decreases the firm's efficiency in our sample.

The pattern of significance in our control variables is consistent with our findings that consignment inventory makes the organization more complex and less efficient. Consistently, our models suggested that larger firms are less efficient. In addition, firms who offer service in core manufacturing areas are also generally less efficient. These services, such as sheet metal forming, do not command as high a premium from customers and thus only serve to decrease the firm's revenue per employee. In addition, firms that offer more distribution services are more efficient than their peers. Our findings suggest that the use of a particular modular organizational structure, consignment inventory, reduces the efficiency of partner firms in an industry where efficiency and operational effectiveness are the basis for competitive advantage.

In analyses not reported, we verified that the influence of consignment inventory is consistent across all levels of efficiency using a simultaneous quantile regression procedure. We estimated the influence of consignment on the lower and upper 20 per cent of efficiency for any given year, and found consistent results through time.

Discussion

Although providing the theoretical motivations for modularity, the modularity literature research has yet to extensively explore empirically the performance implications of such arrangements. While the conceptual research on modular organizational forms generally implies a positive relationship between modularization and firm performance (Baldwin and Clark, 2000; Schilling, 2000), our empirical results suggest that occupying a middle ground between fully integrated and fully modular leads to poor performance and inefficiency. These results show that within the EMS industry, one of the underlying drivers of firm performance is negatively affected by the use of partially modular forms. Entering into partially modular arrangements with OEM firms appears to decrease the efficiency of EMS firms. Within this industry, one not driven by research and development, but rather by operational control, efficiency is a primary driver of performance. We have examined this relationship across a vast selection of firms from within the industry and included smaller, private firms who do not disclose accounting performance information. By testing a broad sample, our findings imply generalizability to the entire industry while also suggesting a deeper understanding of the strategic use of modular arrangements and their implications

Table 1. Variable means, standard deviations and correlation coefficients

Variable	Mean	SD	1	2	3	4	5	6	7	8	9
1. Log of revenue per employee	11.63	0.88									
2. Consignment inventory	17.96	22.06	−0.30*								
3. Automated through-hole technologies	2.52	1.57	0.05	−0.17*							
4. Design capabilities	2.09	1.49	0.12*	−0.17*	0.27*						
5. Distribution capabilities	2.18	0.89	0.12*	−0.17*	0.13*	0.36*					
6. Firm size	0.03	0.94	−0.08	−0.14*	0.17*	0.37*	0.21*				
7. Manufacturing capabilities	4.08	1.21	−0.04	−0.13*	0.24*	0.24*	0.30*	0.11*			
8. Quality control procedures	0.97	0.63	0.12*	−0.25*	0.23*	0.35*	0.34*	0.23*	0.21*		
9. Surface mount technologies	5.24	1.89	0.17*	−0.20*	0.37*	0.32*	0.22*	0.17*	0.21*	0.31*	
10. Testing capabilities	4.59	1.63	0.15*	−0.28*	0.35*	0.49*	0.38*	0.26*	0.38*	0.36*	0.44*

Pooled data with $N = 513$.

*$p < 0.05$.

Table 2. Between-effects regression coefficients

	Log(Revenue per employee)					
	Model 1		Model 2		Model 3	
Automated through-hole technologies	−0.012		−0.006		−0.006	
	(0.038)		(0.036)		(0.036)	
Design capabilities	0.064		0.070		0.070	†
	(0.045)		(0.043)		(0.043)	
Distribution capabilities	0.085		0.065		0.065	
	(0.068)		(0.064)		(0.064)	
Firm size	−0.193	**	−0.201	**	−0.202	**
	(0.074)		(0.070)		(0.070)	
Manufacturing capabilities	−0.135	**	−0.153	**	−0.154	**
	(0.048)		(0.046)		(0.046)	
Quality control procedures	0.150		0.081		0.080	
	(0.093)		(0.089)		(0.089)	
Surface mount technologies	0.052	†	0.048	†	0.048	†
	(0.029)		(0.028)		(0.028)	
Testing capabilities	0.092	**	0.054		0.055	
	(0.043)		(0.041)		(0.041)	
Consignment inventory			−0.011	**	−0.012	**
			(0.002)		(0.006)	
Consignment inventory squared					0.000	
					0.000	
Constant	11.054	**	11.626	**	11.632	**
	(0.214)		(0.228)		(0.232)	
F	4.400	**	7.700	**	6.900	**
R-Squared	0.087		0.153		0.153	

Standard errors reported in parentheses: †$p < 0.1$; *$p < 0.05$; **$p < 0.01$.

within the entire industry rather than just the handful of firms successful enough to go public. By controlling for the effects of time by using five-year averages for our independent and dependent variables, we show that while there is considerable variation between firms, firms tend to remain in the same kind of relationships over time.

We feel there are several additional areas of future research that may help to explain why partial modularization might reduce firm performance. First, modularity research (and much other organizational research) implicitly assumes that firms behave in their own best interest. Recent studies that link environmental and product characteristics to the modular organization decision, for example, tend to assume that firms that become modular do so because it serves the firm at equilibrium. In truth, management research would achieve very little if managers could always be trusted to guide their firms to the best possible course every time and if equilibrium were easy to reach. Schilling and Steensma (2001), for example, suggest that some of the modularization differences they found between firms might be driven by different degrees of managerial risk aversion. Managers might adopt modular forms when they are concerned about the environment, but this concern is shaped

by their risk aversion and environmental perceptions. Other managers might pursue modularization because it simplifies a complex business, making it easier to analyze (Miller, 2002). Like many decisions, the decision to become modular may thus be motivated by at least a manager's risk aversion or desire for simplicity—rather, or in addition to, short-term returns.

Secondly, modularity theory generally conceptualizes inter-firm communication to be facilitated by the increased use of electronic communication and automated systems (Sahaym *et al.*, 2007). However, some research suggests that the use of these systems actually decreases the quality of the relationship between partners, be it within a firm or between a firm and its modular partner (Kraut *et al.*, 1999). Future examinations of modularity theory should examine whether or not loose coupling and lean structures actually improve the quality and standardization of inter-firm communication or if modularity instead fosters insular behavior and hinders cooperation between firms. Our findings suggest that pushing operations that were once housed within the firm to outside parties can reduce the now more modular firm's performance, particularly if that task requires a heightened use of these communication channels (as is true with our measure of "partial" modularity, consignment inventory). Given that some research suggests that these inter-firm linkages harm the quality of the relationship and innovation, future research might investigate the characteristics of functions that should not be pushed to an outside party.

Finally, modularity rests on the ability of firms to outsource particular services and knowledge. Firms may, however, be unable to reintegrate those assets back into the firm later if market conditions change or the modular partner becomes undependable. Firms with partially modular structures may find themselves less able to engage in systemic (versus autonomous) innovation because these depend upon complementary innovations—innovations that under modular arrangements now must take place in other firms (Chesbrough and Teece, 2002). If firms outsource to avoid the need to specialize in particular aspects of their business, they may be unable to gather that knowledge back again if they need it. The decision to modularize may thus in fact be asymmetric. Firms may choose to outsource because they want to be more modular and flexible, but they may not be able to reintegrate (or redevelop) all of their strategic businesses if they decide they need to be less modular. Certain characteristics may increase the likelihood of this asymmetry—for example, the lack of industry standards (Schilling, 2000; Chesbrough and Teece, 2002), the existence of learning or experience economies for a particular process, the degree to which the firms in the market have differentiated capabilities, the speed of technological change (Schilling, 2000; Schilling and Steensma, 2001).

Limitations

This study is subject to several limitations. The use of the EMS industry allowed us to develop a continuous measure of modularity, based on the industry's peculiar consignment inventory option. The industry also allowed us to control for the various differences between product-influenced modularity and technology-influenced modularity, as EMS firms offer an essentially consistent product using similar technological means. Even with similar products and technologies, EMS firms evidence different degrees of organizational modularity, and different levels of performance. However, the use of this closely defined industry may harm

the generalizability of our results. Others have noted that the rarified nature of electronics firms may be one of the problems with modularity research (Ernst, 2005).

In addition, our statistical techniques in this paper are essentially cross sectional. Because most firms in the industry are in long-term contracts with suppliers and customers, the variance in modularity from one year to the next within the same firm is very small. As discussed above, we collapsed our data across years and thus destroyed within-firm variance. Scholars may take exception to this approach, but our intention was to look at the relation between organizational modularity and performance after controlling for complexity. We have accomplished this and shown that more modular firms are also less efficient over the length of our data. Future studies may benefit from examining performance longitudinally and the performance response from changes in modularity within the same firm. Qualitative studies have approached this issue (Frigant and Talbot, 2005), but the literature may benefit from quantitative investigation.

Finally, our study only looked at one side of the relationship in one particular industry. While our findings may not generalize outside the EMS industry, they may also not generalize from the EMS firms to the OEM firms. While EMS firms, after controlling for size, seem to be engaging in actions that hinder their performance, we would be better able to make definitive statements about our findings if we could characterize the OEM firms who contract with the EMS firms. Finally, consignment inventory—the practice of taking a portion of the value chain that was once housed within the firm and moving it to an outside firm—is generally consistent with modularity theory (Schilling and Steensma, 2002). However, it is only one dimension of modularity, and our findings might be more robust if we were to find a more general measure of modularity.

Conclusion

Our findings suggest that firms that engage in more partially modular ties actually lose production efficiency instead of gain it from increased inter-dependency and integration. By examining the performance implications of a particular kind of contract within the EMS industry, we have shown that some modular organizational forms are associated with decreased performance. In this industry, firms engaged in partially modular organization do not perform as well as those that are more traditionally integrated. Managers engaged in partially modular structures should be careful to control the communication and coordination costs that these structures entail (Schilling and Steensma, 2001). While vertical integration and full modularization may both be efficient and effective mechanisms for value creation, there may be no effective middle ground between the two extremes and managers should work to either integrate capabilities back into the organization or establish fixed and robust communication routines when dealing with modular partners.

References

Argyres, N. (1996) Evidence on the role of firm capabilities in vertical integration decisions, *Strategic Management Journal*, 17(2), pp. 129–150.

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

Box, G. E. P. and Cox, D. R. (1964) An analysis of transformations, *Journal of the Royal Statistical Society. Series B (Methodological)*, 26(2), pp. 211–252.

Brusoni, S. and Prencipe, A. (2001) Unpacking the black box of modularity: technologies, products and organizations, *Industrial and Corporate Change*, 10(1), pp. 179–205.

Chesbrough, H. W. and Teece, D. J. (2002) Organizing for innovation: when is virtual virtuous?, *Harvard Business Review*, 80(8), pp. 127–134.

Danneels, E. (2003) Tight–loose coupling with customers: the enactment of customer orientation, *Strategic Management Journal*, 24(6), pp. 559–576.

Ernst, D. (2005) Limits to modularity: reflections on recent development in chip design, *Industry and Innovation*, 12(3), pp. 303–335.

Fleming, L. and Sorenson, O. (2001) Technology as a complex adaptive system: evidence from patent data, *Research Policy*, 30(7), pp. 1019–1039.

Frigant, V. and Talbot, D. (2005) Technological determinism and modularity: lessons from a comparison between aircraft and auto industries in Europe, *Industry and Innovation*, 12(3), pp. 337–355.

Galvin, P. and Morkel, A. (2001) The effect of product modularity on industry structure: the case of the world bicycle industry, *Industry and Innovation*, 8(1), pp. 31–47.

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

Hill, C. W. L. (1990) Cooperation, opportunism, and the invisible hand—implications for transaction cost theory, *Academy of Management Review*, 15(3), pp. 500–513.

Hill, C. W. L., Hitt, M. A. and Hoskisson, R. E. (1992) Cooperative versus competitive structures in related and unrelated diversified firms, *Organization Science*, 3(4), pp. 501–521.

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

Jacobides, M. G. and Winter, S. G. (2005) The co-evolution of capabilities and transaction costs: explaining the institutional structure of production, *Strategic Management Journal*, 26(5), pp. 395–413.

Karim, S. (2006) Modularity in organizational structure: the reconfiguration of internally developed and acquired business units, *Strategic Management Journal*, 27(9), pp. 799–823.

Kraut, R., Steinfield, C., Chan, A. P., Butler, B. and Hoag, A. (1999) Coordination and virtualization: the role of electronic networks and personal relationships, *Organization Science*, 10(6), pp. 722–740.

Lehman Brothers (2002) *Top-Tier EMS at a Glance–September 2002* (New York: Lehman Brothers).

Makadok, R. and Coff, R. (2009) Both market and hierarchy: an incentive-system theory of hybrid governance forms, *Academy of Management Review*, 34(2), pp. 297–319.

Mikkola, J. H. (2006) Capturing the degree of modularity embedded in product architectures, *Journal of Product Innovation Management*, 23(2), pp. 128–146.

Miller, D. and Chen, M. J. (1996) The simplicity of competitive repertoires: an empirical analysis, *Strategic Management Journal*, 17(6), pp. 419–439.

Miller, K. D. (2002) Knowledge inventories and managerial myopia, *Strategic Management Journal*, 23(8), pp. 689–706.

Parmigiani, A. (2007) Why do firms both make and buy? An investigation of concurrent sourcing, *Strategic Management Journal*, 28(3), pp. 285–311.

Pil, F. K. and Cohen, S. K. (2006) Modularity: implications for imitation, innovation, and sustained advantage, *Academy of Management Review*, 31(4), pp. 995–1011.

Powell, W. W. (1990) Neither market nor hierarchy—network forms of organization, *Research in Organizational Behavior*, 12, pp. 295–336.

Sahaym, A., Steensma, H. K. and Schilling, M. A. (2007) The influence of information technology on the use of loosely-coupled forms: an industry level analysis, *Organization Science*, 16(5), pp. 865–880.

Sanchez, R. and Mahoney, J. T. (1996) Modularity, flexibility, and knowledge management in product and organization design, *Strategic Management Journal*, 17(1), pp. 63–76.

Schilling, M. A. (2000) Toward a general modular systems theory and its application to interfirm product modularity, *Academy of Management Review*, 25(2), pp. 312–334.

Schilling, M. A. and Steensma, H. K. (2001) The use of modular organizational forms: an industry-level analysis, *Academy of Management Journal*, 44(6), pp. 1149–1168.

Schilling, M. A. and Steensma, H. K. (2002) Disentangling the theories of firm boundaries: a path model and empirical test, *Organization Science*, 13(4), pp. 387–401.

Staudenmeyer, N., Tripsas, M. and Tucci, C. (2005) Interfirm modularity and its implications for product development, *Journal of Product Innovation Management*, 22(4), pp. 303–321.

Sturgeon, T. J. (2002) Modular production networks: a new American model of industrial organization, *Industrial and Corporate Change*, 11(3), pp. 451–496.

Takeishi, A. (2002) Knowledge partitioning in the interfirm division of labor: the case of automotive product development, *Organization Science*, 13(3), pp. 321–338.

Uzzi, B. (1997) Social structure and competition in interfirm networks: the paradox of embeddedness, *Administrative Science Quarterly*, 42(1), pp. 35–67.

Wooldridge, J. (2002) *Econometric Analysis of Cross Section and Panel Data* (Cambrigde, MA: MIT Press).

Worren, N., Moore, K. and Cardona, P. (2002) Modularity, strategic flexibility, and firm performance: a study of the home appliance industry, *Strategic Management Journal*, 23(12), pp. 1123–1140.