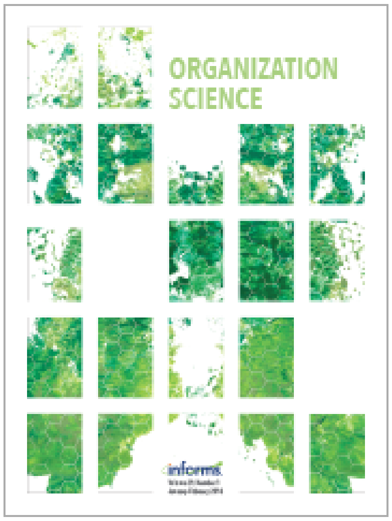

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Yue Maggie Zhou,

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Designing for Complexity: Using Divisions and Hierarchy to Manage Complex Tasks

Yue Maggie Zhou
Robert H. Smith School of Business, University of Maryland, College Park, Maryland 20742,
ymzhou@rhsmith.umd.edu

This paper studies the impact of task complexity and decomposability on the degree of organizational divisionalization and hierarchy within firms. Drawing upon the team theory and modularity literature, it argues that the degree of divisionalization is predicated not only on the extent of interdependence (complexity) among tasks but also on the extent to which those interdependent relationships are decomposable. As such, the feasibility and benefits of modularization in organizational design may be overstated when the underlying tasks are not decomposable. In addition, this paper argues that organizational hierarchy serves to mitigate the tension between complexity and decomposability by facilitating a higher degree of divisionalization. These arguments are tested using data on the business activities and organization structures of U.S. equipment manufacturers in 1993–2003. Results show that divisionalization increases with task complexity, suggesting that complex task systems encourage more division of managerial responsibilities. However, divisionalization decreases as task systems become less decomposable. Meanwhile, organizational hierarchy increases with task complexity, and it increases as task systems become less decomposable. These findings highlight the constraints firms face in designing modular organization structures and the role of hierarchy in coordinating complex task systems that are not fully decomposable.

Key words: division; hierarchy; organization structure; complexity; decomposability; modularity
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Introduction

The division of organization tasks into autonomous organization units, or divisionalization, has been well studied in the classic organization design literature. Divisionalization reduces the cognitive burden on managers by dividing tasks across multiple divisions and allows divisions to specialize and better adapt to their immediate task environment (Chandler 1962, Lawrence and Lorsch 1967, Thompson 1967). The literature further suggests that divisionalization be based on similarity: employees facing similar external environments or task requirements should be grouped into the same divisions, and divisions facing similar external environments or task requirements should be structured similarly from within (Blau 1970, Dewar and Hage 1978).

Although divisionalization facilitates specialization and adaptation, it also generates demand for coordination between divisions, especially when the task structure of the organization is complex, i.e., characterized by extensive interdependencies (Simon 1962, p. 65). When interdependencies among tasks are extensive, the benefits of specialization (in mitigating the cognitive limits of managers) might be outweighed by lost opportunities for coordination across interdependent tasks. On the flip side, minimizing dependencies between tasks would necessitate less divisionalization but at the cost of taxing division managers' cognitive capacity and constraining their ability to adapt to their local environment.

To examine this trade-off between the benefits and costs of specialization and coordination in the divisionalization decision, this paper draws on the emergent modularity literature on complexity. The more complex the task system, the more extensive are the interdependencies and the more difficult it is for individual managers to handle them given constraints on their cognitive capacity. Consequently, there is a greater need for a division of labor through divisionalization. A critical process that facilitates divisionalization is modularization, whereby highly interdependent tasks are encapsulated within divisions and dependencies between divisions are minimized (Baldwin and Clark 2000). Therefore, in addition to complexity, this paper investigates an understudied dimension of "non-simple" interdependencies: decomposability, which describes the *distribution pattern* of interdependencies (Ethiraj et al. 2008, Rivkin and Siggelkow 2007, Yayavaram and Ahuja 2008). A task system is highly decomposable when its tasks can be divided into discrete subsystems, with dense interdependencies within subsystems and sparse interdependencies between them. For a given level of complexity, the more decomposable the task system, the easier it is to modularize and distribute coordination responsibilities across divisions. In contrast, when significant interdependencies exist across task subsystems, a firm with too many divisions is more likely to miss opportunities to coordinate. Hence the benefits of divisionalization through modularization are lower when task systems are less decomposable.[1]

We see from the discussion above that greater divisionalization in a highly interdependent task structure creates an imperative for coordination between the divisions. When bilateral coordination is not sufficient, as in the case of handling extensive interdependencies, hierarchical intervention is needed to resolve conflicts and/or economize on coordination costs (Galbraith 1977, Marschak and Radner 1972, Tushman and Nadler 1978). Thus, hierarchical structures help organizations with complex, nondecomposable tasks manage the tradeoff between the benefits of specialization and the need for coordination. Hierarchical structures use intermediate units such as departments to manage interdependencies between divisions. These intermediate units help the organization obtain the benefits of specialization by encapsulating tasks within the cognitive limits of managers while at the same time using the hierarchy to exploit the benefits of coordination across divisions. This, in turn, enables a greater degree of divisionalization.

I distill the intuition above into four empirically testable hypotheses: (1) greater task complexity leads to greater divisionalization, (2) greater task decomposability leads to greater divisionalization, (3) greater task complexity leads to greater hierarchy, and (4) greater task decomposability leads to lower hierarchy. I use unique data on firms' business activities and organization structures for U.S. equipment manufacturers from 1993 to 2003, as well as advanced network analysis techniques, to test these hypotheses. My results show that divisionalization increases with task complexity, suggesting that complex task systems encourage more division of managerial responsibilities. However, divisionalization decreases as task systems become less decomposable. Meanwhile, organizational hierarchy increases with task complexity, and it increases as task systems become less decomposable. These findings highlight the constraints firms face in designing modular organization structures and the role of hierarchy in coordinating complex task systems that are not fully decomposable.

The key theoretical contribution of this paper is to marry two hitherto unrelated streams of prior work on designing organizations to manage complex tasks. The classic team theory literature elaborates on the role of organization structure in facilitating coordination. But the conceptualization of complexity in this literature has been limited to heterogeneity among individual tasks or pairwise interdependence (Aldrich 1979, Thompson 1967). There has been limited attention to task complexity at the system/corporate level. In addition, task decomposability has rarely been examined. In contrast, the modularity literature operationalizes system complexity and studies its challenges for coordination. However, the solution it prescribes is mainly through modularization. The debates in this literature revolve around the benefits of modular versus integrated structures, with limited attention to the role of hierarchy (Baldwin and Clark 2000, Langlois 2002, Ulrich and Eppinger 1999).[2] By joining these two related strands of literature, this paper expands the scope of theorizing about organization design in general and the use of divisionalization and hierarchy in particular. Specifically, the paper endogenizes two important instruments of organization design—divisionalization and hierarchy—as a function of the complexity and decomposability of the task structure within the firm.

Literature Review

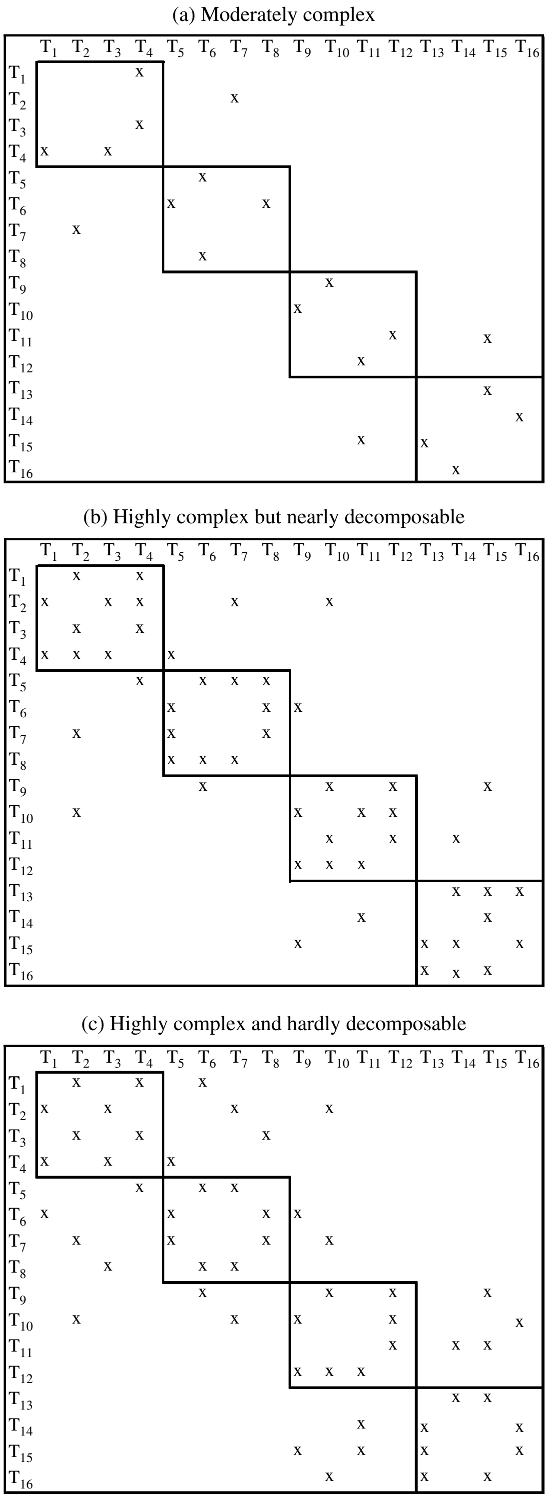
Coordination among agents with congruent incentives entails three key components: information processing, communicating, and deciding (Marschak and Radner 1972, Tushman and Nadler 1978). Along these lines, an emerging literature examines the role of modularity design in coordinating complex task systems among agents with limited cognitive capacity (Baldwin and Clark 2000, Ethiraj and Levinthal 2004b, Rivkin and Siggelkow 2003, Sanchez and Mahoney 1996).

Complex Task Systems and the Modularity Literature

Complex task systems contain a large number of interdependent tasks. The multiple interdependencies impose challenges for coordination. Employees carrying out interdependent tasks must engage in ongoing communication to understand the factors affecting each other's decisions and to track the decisions that are made, particularly when multiple equilibria exist (Arrow 1974, Becker and Murphy 1992). The high number of interactions between decisions also increases demand for information processing (Simon 1955, 1962). Because of the increased workload of communication and information processing, there are more opportunities for decision errors (Levinthal 1997, Sutherland 1980).

The modularity literature conceptualizes firms as systems of activities or tasks that are dependent on one another to varying degrees (Baldwin 2008, Porter 1996). Task systems vary along two important dimensions: the prevalence of interdependencies between tasks and the distribution patterns of those interdependencies. This is often conceptualized using a task matrix. If a firm undertakes N tasks, then a task matrix is an $N * N$ matrix whose entry (i, j) is set to an "x" if column task j affects the outcome of row task i or if changing task j requires changing task i as well. The total number of xs in row i indicates the number of tasks on which the contribution of task i to the overall performance depends, or the number of tasks that need to be coordinated with task i. Figure 1 illustrates three types of task systems, all with the same number of tasks ($N = 16$). For the sake of simplicity, interdependencies are assumed to be

Figure 1 Different Types of Task Systems



reciprocal: the xs are positioned symmetrically above and below the principal diagonal. Figure 1(a) is a system with moderate complexity; it has 20 symmetric connections. Figures 1(b) and 1(c) are more complex; they each have 52 symmetric connections.

Systems with the same degree of complexity—meaning the same number of interdependencies—can have different distribution patterns of interdependencies (Ghemawat and Levinthal 2008, Rivkin and Siggelkow 2007). A highly decomposable task system can be divided into loosely coupled subsystems. For example, the task systems in Figures 1(b) and 1(c) have the same degree of complexity, but the interdependencies are distributed differently. The task system in Figure 1(b) is more decomposable than is the one in Figure 1(c). The xs in Figure 1(b) can be divided into four subsystems (blocks) with few xs in between, whereas the xs in Figure 1(c) are less concentrated: a fair number of them are located between subsystems rather than within subsystems.

Although the modularity literature sheds important light on the challenges that complexity imposes on firms, the solution it proposes is largely limited to redesigning the task systems (and products in particular) rather than the organization structure. Much of the academic focus has been on design rules that aim to increase task system modularity by standardizing product interfaces (Baldwin and Clark 2000, Ulrich and Eppinger 1999). Modularization of task systems is expected to reduce coordination costs between firms and enable more market transactions (Baldwin and Clark 2000, Sanchez and Mahoney 1996), thereby reducing firm scope (Baldwin and Clark 2006, Schilling and Steensma 2001).

Although modularizing task systems facilitates vertical disintegration, whether it also encourages firms to adopt a less integrated and more divisionalized internal structure is not clear. A fundamental advantage of the firm relative to the market is the firm's ability to coordinate interdependent tasks (Monteverde 1995, Williamson 1975). It is possible that as more modularized product and service components and standardized interfaces are shifted out of firms' boundaries, firms are left with fewer but denser or less decomposable interrelationships among tasks. After all, the firm "arises as a nonmodular response to the fact of, or the need for, interactions among the modules" (Langlois 2002, p. 32). Divisionalization becomes challenging if, on the one hand, limitations in managers' cognitive capacity demand specialization, while, on the other hand, the underlying task systems are not decomposable enough to allow effective modularization.

Specialization, Coordination, and the Team Theory

According to team theorists, organizations need to divide tasks and allocate them among subunits (divisions) of agents for three reasons: limited cognitive capacity of individual agents (March and Simon 1958), the pressure to adapt to heterogeneous external environments (Lawrence and Lorsch 1967), and the technological requirements of their tasks (Thompson 1967). Specialization, however, increases the demand for coordination. For example, specialization allows for parallel information processing but increases communication costs and results in delayed or inaccurate joint decisions.

Organizations adopt various means to improve coordination. For example, to improve communication and interpretation among agents, they use organization-specific language, such as meanings, codes, and routines (Arrow 1974, Crémer et al. 2007, Nelson and Winter 1982). Organizations can also reduce the need for communication and calculation through organization identity. Identification with an organization helps agents to internalize the "rules of the game," form stable expectation of others' behavior, and behave consistently (Akerlof and Kranton 2005, Kogut and Zander 1996).

Most importantly, organizations use hierarchical structures to facilitate coordination among subunits. A hierarchical structure serves several functions. First, it establishes an internal information infrastructure, which enables not only the division of communication and processing tasks but also the integration of information for joint decision making. A hierarchical structure (1) allows frontline units to acquire information from their business environments, (2) allows intermediate units to process the information in parallel and transfer it (partially processed) to upper-level management for decision making, and (3) facilitates the relaying of management's instructions to frontline employees (Chandler 1962, Galbraith 1973, March and Simon 1958, Marschak and Radner 1972, Williamson 1967). Through the information infrastructure, the hierarchy also economizes on communication by creating vertical communication channels and eliminating what would otherwise be an unmanageable spaghetti of interconnections (Arrow 1974, Langlois 2002, Zannetos 1965). Middle managers, by sharing the burden of information processing, also bring more information to bear for the firm as a whole (Galbraith 1977).

In addition to an information infrastructure, a hierarchical structure delimitates authoritative lines of command. Subordinates give up their decision rights to supervisors for long-term employment with the firm (March 1994, Simon 1947). Supervisors set priorities when subordinates have different opinions about the use of joint assets (Hart and Moore 2005) and resolve conflicts when subordinates have different expectations of joint efforts (Simon 1991). These distinct roles of a hierarchical structure enhance coordination among subunits.

The team theory literature has largely been focused on divisionalization according to the degree of similarity or heterogeneity in the divisions' environment, whereas the modularity literature is largely concerned with segmenting the organization based on task interdependencies. To be sure, a few exceptional studies (Galbraith 1977, Thompson 1967) do recommend that interdependent tasks be grouped into the same subunit and that a hierarchical structure be adopted when there are substantial between-unit interdependencies. Nevertheless, there has been a limited effort to operationalize and quantify task complexity and decomposability at the system/corporate level. An elaboration of the conflicting demands of task complexity and decomposability on organization structure has been lacking.

Empirical Studies on Organization Structure

Both the modularity and team theory literatures are largely theoretical or rely on computer simulations. Empirical studies are rare. Most empirical studies of organization structure are found in the literature on contingency theory. They generally focus on three issues: the association between technology or environment and structure, the impact of changes in technology or environment on changes in structure, and the performance consequence of a fit between technology or environment and structure (Donaldson 2001). The first issue is often studied using cross-sectional personnel reporting data based on small-scale surveys. After controlling for firm size, the role of technology or environment is often found to be limited (Child and Mansfield 1972). The second issue is often examined based on case studies. Structural innovation is shown to play an important role in accommodating firms' strategic changes (Chandler 1962; Rumelt 1974, 1982). The third issue has been studied with longitudinal data with simplified measures. For example, Hoskisson (1987) compares firm performance before and after the implementation of an M-form structure and finds it only improves performance for unrelated diversifiers but not for related diversifiers or vertically integrated firms. Several reviewers have pointed out that this empirical literature is plagued by a lack of consistency in the choice of constructs and their operational definitions and measures, differences in their levels of analysis, confusion between formal and informal structures, etc., which lead to weak and inconclusive results (Donaldson 2001, Pennings 1992, Scott and Davis 2006).

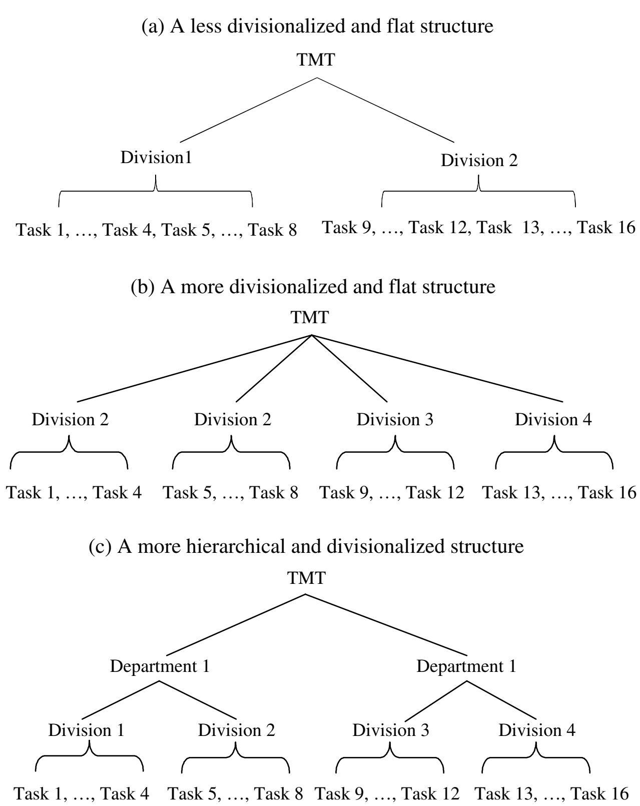
There have been some recent efforts to systematically quantify organization structure for firms across industries. Argyres (1996) measures the degree of divisionalization using the number of product divisions and major manufacturing subsidiaries. Rothwell (1996) calculates a hierarchy index based on the number of layers in the longest line of control from the plant manager to the first line (lowest level) supervisor and the number of people reporting to the plant manager. Rajan and Wulf (2006) count the number of levels between division heads and the chief operating officer (CEO). These studies provide guidance for my measures of organization structure.

Theory and Hypothesis Development

Following prior studies of complexity (e.g., Lenox et al. 2006, Siggelkow and Rivkin 2005, Yayavaram and Ahuja 2008), I treat interdependencies, both their extensiveness and distribution patterns, as inherent relationships between tasks that are dictated by nature rather than chosen by the firm. In contrast, I treat organization structure as a firm decision. I conceptualize organization structure as the partitioning of tasks into organization units (divisions) with connections across units (hierarchy) to facilitate coordination (Mintzberg 1979, Thompson 1967). I make two distinctions between divisionalization and hierarchy in this paper. First, they relate to different structural elements. Divisionalization relates to the most elementary organization units within a structure, whereas hierarchy relates to the organizational interconnections between divisions. Second, the degree of divisionalization and the degree of hierarchy measure two different dimensions of organization structure. The degree of divisionalization measures the extent of horizontal segmentation at the lowest level of organization structure, whereas the degree of hierarchy measures the extent of vertical coordination above the lowest level.

Figure 2 illustrates four types of organization structure, all designed to carry out the same number of tasks ($N = 16$). TMT stands for the top management team, including the CEO, chief financial officer, chief operating officer, etc. The structure in Figure 2(a) has fewer divisions than the structures in Figures 2(b) and 2(c). In addition, the structures in both Figures 2(a) and 2(b) are flat, with no intermediate supervisory units between the TMT and the divisions; the structure in Figure 2(c) is more hierarchical. Division managers coordinate tasks within their divisions, departments coordinate interdependencies between divisions, and the TMT coordinates interdependencies between departments. The more organization units there are between the top management team and the divisions, the more hierarchical is the structure.[3]

Figure 2 Different Types of Organization Structure



In the remainder of this section, I will explore whether there should be a match between task systems (with varying degrees of complexity and decomposability) and organization structures (with varying degrees of divisionalization and hierarchy) that balances the three elements of coordination: communication, information processing, and joint decision making.

Task Complexity and Divisionalization

Interdependence affects divisionalization through two conflicting forces. On the one hand, greater interdependence between two tasks implies greater returns to integrated coordination (rather than divisionalization). On the other hand, an increase in the number of interdependent relationships (complexity) implies more coordination responsibilities for the managers (as bilateral coordination between peer employees becomes more difficult). Because the cognitive capacity of managers is limited, greater coordination responsibilities also necessitate more division of labor and more specialization (as global coordination becomes more difficult; see Parnas 1972, Simon 1962). To facilitate divisionalization, the literature suggests a modularization process through which "the tasks within a multidivisional firm are intentionally designed to require low levels of coordination so that they can be carried out by an organizational structure of quasi-independent divisions functioning as loosely coupled subsystems" (Sanchez and Mahoney 1996, p. 64). Modularization creates at least three benefits. First, it facilitates the division of labor through task partitioning and interface standardization, thereby reducing the need for communication. The interfaces among tasks, once specified, are not allowed to change for a given period of time, during which each division can focus on the group of tasks assigned to it and need not gather or process information about tasks in other divisions (Baldwin and Clark 2000, Cusumano and Selby 1995). Second, modularization provides productive and strategic flexibility through differentiation among divisions, thereby increasing individual divisions' capacity for local information search and processing. Each division, by localizing the impact of its individual tasks and external environments and by counting on the standardized interfaces with other divisions, can learn about and adapt to its environment without fearing disruption (or disrupting) developments in other divisions (Ulrich and Eppinger 1999). Finally, modularization (if matched with decomposable tasks) enhances organization efficiency via embedded coordination, thereby delimitating the scope for joint decision making. Such embedded coordination allows for concurrent and autonomous coordination within loosely coupled divisions based on an information structure and greatly reduces the need for managerial intervention from outside the divisions, thereby reducing the firm's overall managerial responsibilities (Orton and Weick 1990, Sanchez and Mahoney 1996).

Consistent with these benefits, divisionalization guided by a modularization process is particularly useful when interdependencies between elements of the system become so extensive that integrated coordination efforts become almost impossible (Simon 1962). First, as the number of interdependent relationships (task complexity) increases, the number of potential communication channels between agents carrying out interdependent tasks also increases. Partitioning a more complex task system and standardizing feedback channels may reduce communication costs more than partitioning a simpler task system. Second, the more complex the task system, the more difficult it is to achieve adaptation of the entire system. It is therefore even more important to prioritize the interdependencies among tasks and "intentionally" reduce interdependencies between divisions in order to increase their capacity for local information processing and adaptation. Finally, as task complexity increases, the joint contribution of interdependent tasks to the firm's overall performance becomes increasingly difficult to monitor and evaluate. Joint decisions are more difficult; local managerial supervision and intervention will be more frequently requested. Each of these three factors encourages firms to divisionalize according to the modularization process. I therefore propose the following baseline hypothesis.

Hypothesis 1 (H1). *Organizations with a greater degree of task complexity are more divisionalized.*

Task Decomposability and Divisionalization

The modularization process reduces the coordination burden on divisions mainly through embedded coordination and "information hiding": divisions focus on interdependencies between tasks within them and ignore interdependencies with tasks in other divisions (Parnas 1972). Unfortunately, such a local focus may further cognitive and emotional differences across divisions, hindering integration and coordination (Ghoshal and Nohria 1989, Lawrence and Lorsch 1967). For example, a firm with more divisions is less likely to pursue a research and development (R&D) strategy with broad implications for the firm (Argyres 1995). Locally focused divisions also tend to cause maladaptation for the organization as a whole (Ethiraj and Levinthal 2004b, Marengo and Dosi 2005, Siggelkow and Rivkin 2006).

Ideally, to reduce an organization's overall coordination burden, the boundaries of its units should coincide with the technical boundaries of its tasks, and the interactions between units should coincide with the technical interdependencies between tasks (Thompson 1967). As task systems become less decomposable, the number of interfaces increases. All else equal, a greater number of interfaces is more difficult to standardize than is a smaller number of interfaces. With a greater number of nonstandardizable interfaces, divisionalization will result in more interdependencies between divisions. The increase in interdependencies brings back the demand for information sharing (communication) between divisions that modularization was intended to avoid. Such communication is often rich, multilateral, and intense, involving substantial face-to-face discussion and direct observation (Wheelwright and Clark 1992). These communication requirements are more easily fulfilled in a more integrated (less divisionalized) organization structure (Puranam 2001). Employees in the same division share a more homogeneous communication system than do employees in different divisions (Dougherty 1992). They are also influenced by more homogeneous incentive regimes that encourage knowledge sharing (Zenger and Hesterly 1997) and similar authority structures that reduce the need for repetitive, horizontal communication between multiple parties (Simon 1947). Therefore, interdependent tasks are more likely to be integrated in the same unit than to be separated into two units (Puranam 2001, Thompson 1967).

Greater interdivision interdependencies caused by lower levels of task decomposability also require more intensive managerial intervention across divisions because modifying decisions and actions in one division will require more compensating modifications in interdependent divisions than in independent divisions. Therefore, a lack of decomposability in a task system will reduce the adaptive, communicational, and coordinative benefits of a modularization process. Task systems composed of less decomposable elements will require a more integrated (less divisionalized) organization structure.

Hypothesis 2 (H2). *Organizations with a greater degree of task decomposability are more divisionalized.*

Task Complexity, Task Decomposability, and Organizational Hierarchy

Hypotheses 1 and 2 contend that the higher coordination needs of more complex and less decomposable task systems cannot be met by divisionalization *alone*. To complement divisions, organizations can use hierarchy to enhance overall coordination. Organizations benefit from hierarchical structures when there are substantial interdependencies between subunits. Compared with a flat structure, a hierarchical structure improves all three elements of coordination. It changes a horizontal web of information sharing between subunits into vertical reporting channels, which economizes on communication (Arrow 1974, Langlois 2002, Zannetos 1965). It allows independent and parallel information aggregation by intermediate units, thereby reducing the workload for central decision makers (Radner 1993) and enhancing the organization's overall capacity for information processing (Galbraith 1977). For example, it saves the CEO's attention for low-frequency, between-unit interactions that yield firmwide benefit after high-frequency interactions have been dealt with by unit managers within their respective units (Harris and Raviv 2002). Furthermore, by taking into account task interdependencies across subunits, a hierarchical structure reduces the probability of decision errors and improves decision quality. For example, when division managers divide up the task of resource allocation, they tend to consider only information about the costs of workshops under their direct supervision and ignore potential synergistic cost-saving opportunities with other divisions. Only their common supervisor will attend to these opportunities and lower the joint production cost (Geanakoplos and Milgrom 1991).

Substantial interdependencies are more likely to arise between divisions when an organization's task system is more complex. First, the more complex the task system, the more prevalent are the interdependencies. Conditioned on the number of divisions, a higher level of complexity will create a greater number of interdependent relationships between divisions. In addition, as argued in H1, the more complex the task system, the more divisions are required to achieve adaptive, communication, and coordination benefits as well as to share the coordination responsibilities. This increases the number of divisions, leaving more interdependencies between them.

According to Galbraith and Lawler (1993), the more imperative the need for lateral coordination between subunits, the greater the need for hierarchical intervention that deals with increasingly aggregated levels of the organization system, especially when complex tradeoffs exist. For example, if the divisions (each in charge of a subsystem of tasks) are highly interdependent because they share resources, technology, or customers, it is important for their common supervisors to forge business directions (regarding common technology and product strategy) so that the divisions' operations do not conflict with each other. In addition, for issues that cannot be resolved laterally between divisions, a common boss helps to speed up or finalize joint decisions and allows uncertainties to be resolved more quickly. Furthermore, the more extensive the between-division interdependencies are, the less likely it is that a single manager can handle them alone. A hierarchical structure helps to "simplify the process of achieving collective action when large numbers of people are interdependent" (Galbraith 1993, p. 9). A number of divisions can be grouped into one department until they exceed the span of control of the department manager; then a few more departments can be added to exhaust the remaining divisions (Galbraith and Nathanson 1978).

I therefore propose the following hypothesis.

Hypothesis 3 (H3). *Organizations with a greater degree of task complexity are more hierarchical.*

In contrast, substantial interdependencies are less likely to arise between divisions when the task system is more decomposable. Conditioned on the level of task complexity, the more decomposable the task system, the fewer interdependencies will be left between, rather than within, the divisions. In such cases, divisions suffice to handle interdependencies within the task subsystems and there is less need for hierarchical coordination from a higher level (Nadler and Tushman 1997). Therefore,

Hypothesis 4 (H4). *Organizations with a greater degree of task decomposability are less hierarchical.*

In sum, the four hypotheses suggest that organizational divisionalization increases with task complexity and task decomposability, whereas organizational hierarchy increases with task complexity but decreases with task decomposability. There are certainly boundary conditions to these hypotheses. In theory, when task complexity is extremely low and tasks are fully decomposable, the hypotheses predict a medium level of divisionalization (because low complexity and high decomposability offset each other's impact on divisionalization according to H1 and H2) and an extremely low level of hierarchy (because low complexity and high decomposability reinforce each other's impact on hierarchy according to H3 and H4). However, we might not empirically observe such a case. This is because the task system is so noncomplex (simple) and decomposable that it will probably be disaggregated between rather than within firms (assuming that complexity is one motive for internalization of activities). Because my study examines organization structures within firms rather than between firms, it focuses on tasks that are *integrated* by the firm, which are likely to be cospecialized within the same firm and have nontrivial interdependencies among them. So the extreme case of simple and fully decomposable task systems is outside the scope of my sample and my study.

Methods

Most prior work in the modularity and team theory literature relies on theoretical modeling or computer simulations. There is a dearth of empirical tests because (1) the key constructs are difficult to operationalize and measure, and (2) information on firms' internal activities and structures is hard to obtain. This paper addresses some of these empirical challenges.

Identifying Task Systems

Complexity exists at multiple levels within firms. For tractability, this paper focuses on interdependencies within a firm's activity system and abstracts from interdependencies in a broader organizational context.

The task system in this paper refers to the network of value-chain activities interrelated through physical input–output feedback loops that transfer and transform information and materials (Baldwin 2008, Porter 1985, Sturgeon 2002). Physical transfers and transformations happen through production, distribution, or auxiliary activities. They do not capture all firm tasks, but they illuminate dependencies among other firm tasks. For example, design and manufacturing tasks are often closely related; manufacturing engineers are integrated with the design team to conduct in-depth reviews to assess the productivity of designs in process, and design/manufacturing teams remain integrated for a long time (up to several years) after a product has gone into manufacturing in order to refine the fit between the product and the manufacturing process and improve manufacturing quality or reduce costs (Adler 1995). At Toyota, a design change the styling department proposed for the front panel of a new Celica model prompted the manufacturing department to experiment with retooling and modify the proposed design of the front panel (Rivkin and Siggelkow 2006). Compared with product-design architecture, the production system involves the transfer of information and decisions as well as materials; it is therefore a richer representation of the firm as a system of interdependent tasks (Baldwin 2008).

Data and Sample

The empirical analyses were conducted on U.S. equipment manufacturers in Standard Industrial Classification (SIC) codes 34–38 between 1993 and 2003. The level of analysis is firm-year. Firms in SIC codes 34–38 produce fabricated metal products, industrial machinery and equipment, electrical and electronic equipment, transportation equipment, and instruments and related products. This empirical setting is especially suitable because equipment manufacturing entails multiple stages and requires large quantities of intermediate inputs, providing large variation in production tasks across firms in the same primary industry. According to data provided by the U.S. Bureau of Economic Analysis (BEA 2011), equipment manufacturers produce about \$1.6 trillion of output in terms of shipment value, or 30% of the output produced by all manufacturing firms.

Information about firms' organization structures and business activities was drawn from the Directory of Corporate Affiliations (DCA) offered by LexisNexis. DCA provides reporting information on parent companies and their units (e.g., groups, departments, divisions, subsidiaries, branches), down to the seventh level of corporate linkage, for firms that have more than 300 employees and \$10 million in revenue (LexisNexis 2005). In addition, the data set describes up to 30 segments (four-digit SICs) for each unit. The data set is compiled from information reported by the companies as well as from annual reports and business publications in the LexisNexis database. In addition, each company is contacted directly for information verification. The DCA data set for publicly traded U.S. firms from 1993 to 2003 contains 2,075 parent companies whose primary industries are in SIC codes 34–38.

Financial information was extracted from Compustat. The data sets were matched by parent company names first using a software program and then using manual checks. Ambiguous matches were further verified via company websites. A total of 1,621 companies (78%) in equipment manufacturing sectors was matched. I dropped firms for which there were missing values in Compustat. In addition, because the focus of my study is coordination across business segments and organization units, I dropped firms that reported only one segment or only the headquarters in their organization structure. My final sample contained 1,029 firms and 5,307 firm-year observations.

Dependent Variables: Divisionalization and Hierarchy

I constructed measures of divisionalization and hierarchy based on the small body of prior work that systematically quantifies organization structure for firms across industries. Following these studies, I measured the two dimensions of organization structure using organization charts. I defined divisionalization as the number of divisions and majority-owned subsidiaries that have no subordinate divisions or subsidiaries. These divisions and subsidiaries represent the lowest level of profit-center responsibility and therefore can be compared across firms (Argyres 1996, Rajan and Wulf 2006). I included majority-owned subsidiaries to account for business units that are of a separate legal form but make significant contributions to the parent firm's revenue and coordination responsibilities (e.g., GE Capital).

To measure organizational hierarchy, I took into account the number of layers in organization charts. But to capture firms' aggregated capacity for hierarchical coordination, I summed the number of supervisory units (departments, groups, etc.) on each layer that have at least one subordinate unit (another department, group, division, or subsidiary) and multiplied them with the rank of the layer in the hierarchy. With the same number of layers, firms that have more supervisory units will have a greater value for organizational hierarchy.[4]

Independent Variables: Task Complexity and Decomposability

Both task complexity and decomposability were constructed based on the presence of interdependencies between business segments within firms. I adopted Thompson's (1967) definition of sequential and reciprocal interdependencies and defined two business segments as interdependent if they supply significant inputs to one another. Such interdependencies often entail mutual adjustments and adaptation, thereby requiring coordination. I used the BEA Input-Output (IO) "Use" tables. The tables contain the value of pairwise commodity flows among IO industries and can be converted to commodity flows among SIC industries through an IO–SIC concordance (Fan and Lang 2000). They are updated every five years. Because BEA changed the IO industry coding system in 1997, I used the tables for 1992 to ensure comparability. Except for the code change, coefficients in the tables have been fairly stable over time (Fan and Lang 2000, Hortaçsu and Syverson 2009). Even though I used the same IO tables for all years, firms in my sample have different values for task complexity and decomposability from year to year as their business portfolios change.

For each firm-year, I constructed a task matrix. If a firm operates N business segments in a given year, the task matrix is an $N * N$ matrix whose entries (i, j) and (j, i) are set to xs if segments i and j, on average, contribute more than 1% of the input to one another according to the IO tables.[5] Based on the task matrices, I then calculated the measures for task complexity and task decomposability.

Task complexity is the number of segment pairs in the firm's portfolio that are interdependent with each other, or the number of xs in the task matrix. The measure corresponds to the theoretical definition of complexity in the modularity literature (Baldwin and Clark 2000, Kauffman 1993, Levinthal 1997). Similarly, Burton and Obel (1980) use a computer-simulated IO table to measure technological complexity.

Task decomposability represents the decomposability of the task system, or the task network. To construct the measure, I drew insights from the network analysis literature, which recognizes that real-world networks are often composed of tightly knit "clusters" or "communities" (Zhang and Zhang 2009). Newman and Girvan (2004) give a formal definition of the community structure of a network. In brief, when the nodes of a network are separated into any number of communities, one can compute a D value for that particular separation as the following:

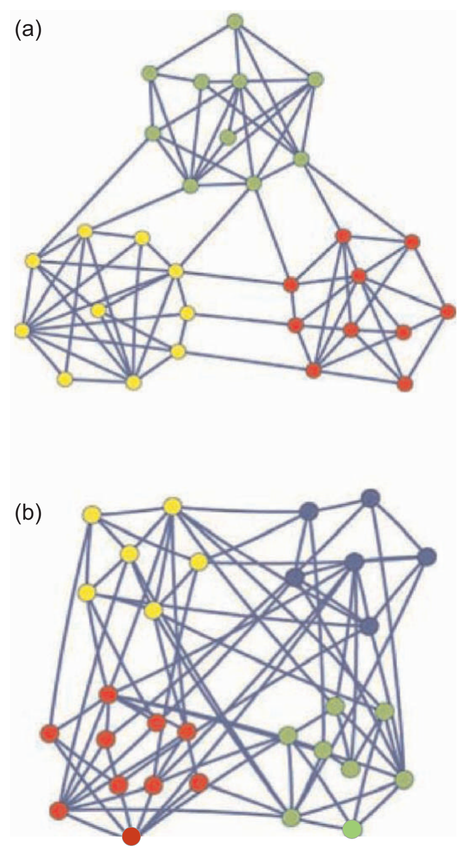
$$D = \sum_{s=1}^{K} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right], \tag{1}$$

where K is the number of communities, L is the total number of edges in the network (or xs in the task matrix), l_s is the number of edges between nodes within community s, and d_s is the total number of degrees of the nodes in community s. The degree of a node is its number of edges. In essence, D is the difference between the observed and expected proportions of within-community edges in the network. Here, the expected proportion is computed from a random network where edges are equally likely to be within and between communities. The highest D value of all possible community separations is called the network decomposability.

Several techniques have since been developed to empirically identify the communities in a network. Among them, an algorithm developed by Guimerà and Amaral (2005) has been shown by empirical and simulation studies to perform the best because it provides the most accurate community separation and the highest D value (Danon et al. 2005). The algorithm is now widely used in network analyses. Figure 3, reproduced from Wang and Zhang (2007), provides an illustration. The two networks, A and B, have the same number of nodes and edges. For each node in A, there is a correspondent node in B with the same number of degrees. The only difference between networks A and B is the distribution of the edges. Colors in each network represent the separation of the nodes into communities that will result in the highest D value as defined in (1). Under the separation presented in Figure 3, network A has a D value of 0.54, whereas network B has a D value of 0.28; A is therefore more decomposable than B.

Here, I used the Guimerà and Amaral (2005) algorithm to calculate the decomposability of the task networks. Each node in a network represents a task; each

Figure 3 More vs. Less Decomposable Task Systems



Note. The figure is reproduced from Wang and Zhang (2007) with permission.

edge represents an inherent interdependent relationship. A task system represented by network A in Figure 3 is more decomposable: the tasks can be grouped into three distinctive communities, each being coordinated by a division manager. In contrast, a task system represented by network B is less decomposable: a separation of the network that will generate the highest D value still leaves out significant interdependencies between the divisions. In this case, too many divisions will cause the coordination efforts to be more fragmented than what the underlying task system demands, thereby sacrificing significant amounts of coordination benefits between the divisions. Therefore, the network in B will require a less divisionalized or more hierarchical organization structure to manage than will A (Figures 2(a) or 2(c), respectively, depending on the cognitive capacity of the divisions).

One limitation of the Guimerà and Amaral (2005) algorithm is that it only calculates the D value for connected networks. When a network has more than one component (subnetwork that is disconnected from other subnetworks), the algorithm calculates the D value for the largest component, ignoring all other components. About half of the task systems in my sample have more than one component (including isolated nodes), and the largest component on average contains a majority (84%) of the nodes in the task system. I therefore defined task decomposability as the following:

$$\begin{aligned}&\text{Task decomposability}\\&\quad = D\cdot\text{No. of communities in the largest component}\\&\qquad +\text{No. of components in the task network}-1, \qquad (2)\end{aligned}$$

where the D value is defined in Equation (1) above and calculated using the Guimerà and Amaral algorithm for the largest component. Given the number of links in a network, the more components a task system has, the more decomposable it is. In addition, the more separable communities the largest component has, the more decomposable the network is. I identified all components using a breadth-first search algorithm (Knuth 1997).

Constructing task matrices from the IO tables offers several benefits. First, it is close to the theoretical representation of task systems (see Figure 1). It also reflects the concept of firms as webs of feedback loops among inputs and outputs for value-chain activities, such as the design and production of chip, disk, battery, motherboard, and screen in notebook production (McKelvey 1999). Second, because firms in the same primary industry have different portfolios in time, they have different task systems and therefore different values for task complexity and decomposability, generating both cross-sectional and longitudinal variations and allowing me to compare task complexity and decomposability consistently across firms and over time. Finally, the time-varying nature of the measures allows me to implement econometric analyses that partially address the problem of unobserved heterogeneity across firms.

The assumption underlying this approach is that potential interdependencies among activities are determined at the economy level, but firms have a choice of whether to exploit a particular interdependence. In other words, there is the exogenous potential for interdependencies between activities, but firms can affect interdependencies in their specific systems by their choice of activities (Lenox et al. 2006). If a firm integrates two activities that can potentially supply significant amounts of inputs to one another, rather than transacting through the market, I infer that inside this particular firm, the requirements of these two activities are cospecialized, and the two activities are interdependent. In contrast, if the firm integrates only one activity and leaves the other outside its boundary, I infer that the firm has chosen to standardize its requirement of the excluded activity and has made it not highly interdependent with the integrated activity in order to make it procurable from the market. Certainly, segments within a firm may choose to share and supply inputs more or less than the average flow of inputs at the industry level. My less-than-fine-grained measures result in measurement errors that may cause an attenuation bias toward zero and make my results more conservative. Similar measures of interindustry relationships in production inputs (Lemelin 1982), human capital (Chang 1996, Farjoun 1998), or technology (Robins and Wiersema 1995) have been used by economists and strategy scholars to proxy intersegment relationships within firms. In particular, the use of IO table coefficients as proxies for intersegment relationships within diversified firms has been adopted by recent studies in economics, finance, and strategy (Fan and Lang 2000, Matsusaka 1993, Schoar 2002, Zhou 2011).

Along with the factor variables of task complexity and decomposability, I included several control variables that may affect a firm's organization structure. Empirical evidence abounds for a link between industrial diversification and multidivisional form (MDF; see, e.g., Fligstein 1985). A link between geographic diversification and MDF has also received some support (Grinyer et al. 1980). In general, firm size has been found to have a significant impact on organization structure (Child and Mansfield 1972). I therefore controlled for firm scope—both in terms of industrial (number of business segments) and geographic (number of countries) diversity—as well as firm size.[6]

Because hierarchical structures have the potential to slow down decision making along the vertical chain, as well as the potential for knowledge appropriation by middle managers, firms in more volatile environments and knowledge-intensive industries are argued to have less hierarchical structures (Rajan and Zingales 2001, Van Zandt 2003). I therefore controlled for volatility (the absolute beta of firms' stock returns) and knowledge intensity (R&D expenditure per dollar of sales revenue).

Table 1 provides descriptive statistics of the sample. It shows that an average firm has 5.4 (exp(1.7)) divisions. In untabulated statistics, I also find an average firm has 2.2 supervisory units, distributed over two to seven layers of corporate hierarchy (the average number of layers is 2.4). On average, firms have 28 interdependent segment pairs. The average firm has 1,733 ($1000 \cdot \exp(0.55)$ employees and operates in about 7.8 segments and 2.9 (exp(1.06)) countries. Table 1 also presents the correlations between the variables.

Model Specification

I adopted a firm fixed effects model to estimate the impact of task complexity and decomposability on organization structure:

$$OrgStructure_{it} = a_0 + a_1 \cdot TaskComplexity_{it} + a_2 \cdot TaskDecomplexity_{it} + X_{it} + \varepsilon_{it}, \quad (3)$$

where *OrgStructure* refers to divisionalization for H1 and H2 and hierarchy for H3 and H4. X_{it} is a vector of control variables, and ε_{it} is a firm-specific error term. The fixed effects models difference all the variables from their mean values and remove unobserved heterogeneity that is constant over time, thereby mitigating the issue of potential endogeneity. Furthermore, because divisionalization and hierarchy are two dimensions of the same organization structure, they can be subject to common shocks. To allow correlated errors between equations, I adopted a seemingly unrelated regression system (Zellner 1962). H1 predicts $\alpha_1 > 0$, H2 predicts $\alpha_2 > 0$, H3 predicts $\alpha_1 > 0$, and H4 predicts $\alpha_2 < 0$.

Results

Table 2 shows the relationship between task complexity, task decomposability, and organization structure. Model 1 includes only the control variables for the estimation of both divisionalization and hierarchy. Model 2 adds task complexity, and Model 3 adds task decomposability.

Looking across models, coefficients for the control variables are fairly consistent and mostly in the expected direction. Firm size, firm scope, and geographic coverage all have a positive effect on both divisionalization and hierarchy. Volatility has a negative impact, although the impact is not always significant. R&D has a negative impact on divisionalization but no significant impact on hierarchy.

Models 2 and 3 show that task complexity has a positive and statistically significant impact on both divisionalization and hierarchy, as suggested by H1 and H3. Based on Model 3, increasing task complexity by a standard deviation will increase divisionalization by 0.25 ($50.28 \cdot 0.005$) or the number of divisions by 28% ($\exp(0.25) - 1$). At the same time, increasing task complexity by a standard deviation will increase hierarchy by 0.15 ($50.28 \cdot 0.003$) or the weighted number of supervisory units by 16% ($\exp(0.15) - 1$).

Model 3 reports the additional effect of task decomposability on organization structure. It shows that task decomposability has a significant and positive impact on divisionalization and a significant and negative impact on hierarchy, as predicted by H2 and H4, respectively. Based on the coefficients, increasing task decomposability by a standard deviation will increase divisionalization by 0.04 ($1.12 \cdot 0.035$) or the number of divisions by 4% ($\exp(0.04) - 1$). In contrast, increasing task decomposability by a standard deviation will reduce hierarchy by

Table 1 Summary Statistics

Variables	Definition	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) *Hierarchy*	Log(number of supervisory units multiplied by their rank)	2.35	0.50	1.00								
(2) *Divisionalization*	Log(number of base divisions and subsidiaries)	1.68	1.15	0.58*	1.00							
(3) *Task complexity*	Number of segment pairs that supply more than 1% input to one another	28.45	50.28	0.71*	0.64*	1.00						
(4) *Task decomposability*	As calculated in Equation (2)	1.02	1.12	0.09*	−0.05*	−0.002	1.00					
(5) *Firm scope*	Number of segments: four-digit SICs	7.80	9.36	0.71*	0.61*	0.90*	0.12*	1.00				
(6) *Geographic dispersion*	Log(number of countries)	1.06	1.04	0.46*	0.77*	0.53*	−0.19*	0.47*	1.00			
(7) *Firm size*	Log(thousand employees)	0.55	1.79	0.55*	0.66*	0.62*	−0.04*	0.60*	0.56*	1.00		
(8) *Volatility*	Absolute beta of stock returns from year $t-3$ to $t-1$	0.98	0.93	−0.05*	−0.04*	−0.05*	−0.12*	−0.08*	0.07*	0.03*	1.00	
(9) *R&D intensity*	R&D expenditure/sales	0.06	0.07	−0.15*	−0.13*	−0.11*	−0.20*	−0.15*	0.08*	−0.16*	0.32*	1.00

Note. $N = 5{,}307$.
$^*p < 0.1$.

Table 2 Impact of Task Complexity and Decomposability on Organization Structure

	Model 1		Model 2		Model 3	
	Divisionalization	Hierarchy	Divisionalization	Hierarchy	Divisionalization	Hierarchy
Task complexity (H1/H3)			0.004***	0.003***	0.005***	0.003***
			[0.001]	[0.001]	[0.001]	[0.001]
Task decomposability (H2/H4)					0.035***	−0.022***
					[0.009]	[0.005]
Firm scope	0.026***	0.016***	0.009***	0.006***	0.008***	0.006***
	[0.002]	[0.001]	[0.002]	[0.001]	[0.002]	[0.001]
Geographic dispersion	0.735***	0.129***	0.722***	0.121***	0.725***	0.120***
	[0.014]	[0.009]	[0.014]	[0.009]	[0.014]	[0.009]
Firm size	0.098***	0.034***	0.094***	0.031***	0.091***	0.033***
	[0.011]	[0.007]	[0.011]	[0.007]	[0.011]	[0.007]
Volatility	−0.011	−0.002	−0.012*	−0.003	−0.012*	−0.003
	[0.007]	[0.004]	[0.007]	[0.004]	[0.007]	[0.004]
R&D intensity	−0.375***	0.099	−0.381***	0.095	−0.383***	0.096
	[0.135]	[0.084]	[0.133]	[0.082]	[0.133]	[0.082]
Constant	0.001	0.002	0.001	0.002	0.001	0.002
	[0.004]	[0.002]	[0.004]	[0.002]	[0.004]	[0.002]
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,307	5,307	5,307	5,307	5,307	5,307
Number of firms	1,029	1,029	1,029	1,029	1,029	1,029
R^2	0.43	0.13	0.44	0.15	0.45	0.15

Notes. Seemingly unrelated regression of divisionalization and hierarchy for U.S. equipment manufacturers from 1993 to 2003. Robust standard errors clustered at the firm level are in brackets.

*Significant at the 10% level; **significant at the 5% level; and ***significant at the 1% level for two-tailed tests.

0.02 $(1.12 \cdot (-0.022))$ or the weighted number of supervisory units by 2% $(\exp(-0.02) - 1)$.

Equation (3) assumes that firms design their divisions and hierarchy concurrently based on task complexity and task decomposability (and other firm-specific characteristics). That said, because of constraints unobservable to econometricians, firms may actually stage their structure decisions. For example, a firm may establish a division to handle a group of tasks and only later establish a supervisory unit to handle the relationship between the newer and older divisions. If that is the case, given task interdependencies, the amount of coordination needed between divisions may be a function of divisionalization. To account for this possibility, in robustness checks I added divisionalization as a control variable in the estimation of hierarchy. The results show that, as expected, the number of divisions was positively correlated with hierarchy. After controlling for the number of divisions, the positive impacts of firm scope, geographic coverage, and firm size on hierarchy all became weaker but remained statistically significant. The impact of task complexity and decomposability was similar and remained statistically significant.

To further account for unobservable factors that jointly impact divisionalization and hierarchy, all of the regressions in Table 2 include firm fixed effects. Of course, fixed effects models will not remove unobserved heterogeneity that varies with time. Given that my paper is already fairly complex in both theory and empirical design, and because there are no valid instruments in my data sets to solve the endogeneity issue beyond fixed effects models, this is an issue better left for future study.

In sum, the results in Table 2 confirm that divisionalization increases with task complexity but decreases as task systems become less decomposable. Meanwhile, organizational hierarchy increases with task complexity but decreases as task systems become more decomposable. These results are consistent with the hypotheses.

Discussion and Conclusion

This paper investigates the relationship between firms' task systems and their organization structures. It focuses on two key dimensions for both: the complexity and decomposability of task systems and the divisionalization and hierarchy of organization structures. Empirical analyses of the business activities and organization structures of U.S. equipment manufacturers between 1993 and 2003 show that firms with complex and decomposable task systems favor more divisions. In addition, hierarchy coexists with divisions in firms with complex but nondecomposable task systems.

The key theoretical contribution of this paper is to marry two hitherto unrelated streams of prior work on designing organizations to manage complex tasks. As MacDuffie (2006, p. 11) points out, "The primary theorists of modularity at a systems level . . . don't provide clear guidance for how to characterize intermediate points along the range from modular to integral." There is the need to recombine the activities divided across organization units and ensure fit at the firm level (Puranam 2001). While the classic design literature elaborates on the role of organization structure in facilitating coordination among complex tasks, the conceptualization of complexity has been limited to heterogeneity among individual tasks or pairwise interdependence. By joining the classic design literature and the more recent modularity literature, this paper expands the scope of theorizing about organization design in general and the use of divisionalization and hierarchy in particular. Specifically, the paper endogenizes two important instruments of organization design—divisionalization and hierarchy—as a function of the complexity and decomposability of the task structure within the firm.

In addition, neither the team theory literature nor the modularity literature has adequately examined the impact of nondecomposability on firms' internal structure. Recent findings that the potential for modularization varies across organizations suggest that modularization is not universally appealing and that a search for alternative structural designs is warranted (Ethiraj and Levinthal 2004b, Hoetker 2006, Yayavaram and Ahuja 2008). This paper highlights the inherent tension between task complexity and task decomposability. A firm's ability to modularize its structure, therefore, depends ciritically on the decomposability of its underlying task system.

Finally, by focusing on the tension between task complexity and task decomposability, this paper underscores both the trade-off that managers face when designing modular organization structures and the relevance of hierarchy. It examines a boundary condition for the notion of "flatter organizations" that is well documented in the popular press and academic research (e.g., Rajan and Wulf 2006, *Economist* 1990). The finding that firms use hierarchy to manage complex tasks does not mean that organizational hierarchies have become steeper. Rather, it means that firms with more complex, but less decomposable, task systems have more supervisory units. It is likely that these units are located across a fewer number of layers as a result of the flattening process. Although removing layers may reduce firms' response time, firms still need enough intermediate units to coordinate their divisions.

The paper has a few limitations that provide opportunities for future studies. First, an organizational modularization process is intended to determine not only the number of modules (or divisions) but also the connections between and within the modules (Baldwin and Clark 2000, Ethiraj and Levinthal 2004b). This paper hypothesizes and empirically examines the growth in the number of divisions but does not study the connections between or within them. This is partly due to data constraints: I do not have sufficient information to measure the bilateral connections or coordination efforts between divisions. A natural extension of this paper is to collect information on coordination interdependencies between divisions and construct a measure of organizational modularity similar to the measure of task decomposability in this paper (except that exogenous task interdependencies will be replaced with endogenous coordination interdependencies). This extension could present a more complete picture of organizational modularity.

In addition, this paper treats task systems as predetermined and studies their impact on future structural design. It does not investigate why some firms choose to integrate complex activities whereas others standardize and outsource them. Although firms can certainly alter their task systems to reduce coordination costs, the literature suggests that firms often make decisions about tasks based on factors other than coordination. For example, firms may diversify into related business segments to seek synergies, which unfortunately also increases the complexity of their task systems (Zhou 2011). Firms may integrate certain activities to leverage their core competencies into adjacent value chain activities (Leiblein and Miller 2003), to insulate their multistage production processes from environmental perturbations (Thompson 1967), to facilitate coordination at the activity level (Monteverde 1995, Williamson 1975), to accommodate differential positioning strategies for their products (Argyres and Bigelow 2010), or to preserve an integral knowledge of product architecture that deters imitation (Ethiraj et al. 2008, Fleming and Sorenson 2001). These corporate, product, and R&D strategies may constrain firms from adopting non-complex or decomposable task systems and present opportunities for structural design at the organizational level. The current study does not argue against these justifications for integration. Rather, it points out that the choice between integration and outsourcing, because it changes firms' task systems, may have an impact on the design of organization structure. A natural extension of this paper is to study how firms endogenously design their task systems and organization structures to enhance coordination.

Finally, although firms coordinate through both formal and informal structures, this paper focuses on formal structure only. Unofficial communication, trust, routines, networks, and other informal structures facilitate important functions that cannot be easily dedicated to a formal structure. Nevertheless, as Nickerson and Zenger (2002) point out, a firm's formal structure strongly affects the shape of its informal structure because the latter often develops in response to the former; there is also a great deal of overlap between the two. For example, the operation of an informal network among individuals in an organization is influenced by the position of those individuals in the organization's formal hierarchical structure (Brass 1984). In addition, informal roles do not convey the same degree of formal empowerment and legitimacy to the coordinator (Galbraith and Lawler 1993). Furthermore, the more frequent the interactions between subunits, the less likely that a formal hierarchical structure can be replaced with cross-functional project teams and committees, because these transitory structures offer less adequate coordination and more confusion in authority (Galbraith and Lawler 1993). An extension of this paper could be to study how firms use both informal and formal structures to manage complex and nearly decomposable tasks.

In sum, this paper highlights the constraints firms face in designing modular organization structures and the role of hierarchy in coordinating interdependencies between subunits. In addition to the theoretical contributions and practical implications highlighted herein, the paper provides empirical evidence of task systems affecting organization design using a unique data set with a large sample of real firms and advanced network analysis techniques. It will, I hope, encourage more empirical studies to complement the extensive theoretical modeling and simulation efforts in the literature on complexity and organization structure.

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Endnotes

[1]To be sure, task systems vary not only in terms of complexity and decomposability but also in many other features. They can also be hierarchical to various degrees. It is worth noting that there are at least two meanings of hierarchy in the literature: the hierarchical structure of the task system and the hierarchical structure of the organization/firm. The hierarchical structure of the task system captures the directionality of interdependence among tasks or subsystems (Ethiraj and Levinthal 2004a, Simon 1962). The hierarchical structure of the organization, on the other hand, represents the vertical structure that coordinates between organization units (Holmstrom and Tirole 1989). As such, organizational hierarchy does not imply that the task system is hierarchical. Structural features of the task system other than complexity and decomposability, including hierarchy, are computationally difficult to measure and are excluded from the current study.

[2]There are a few exceptional studies that recognize the importance of hierarchy in dealing with complexity. For example, Rivkin and Siggelkow (2003, 2005, 2006) examine the delegation of decision rights or information processing responsibilities within a structure of one CEO and two managers. The current paper differs from these studies in that, first, it does not study the allocation of coordination responsibilities within a given structure. Rather, it investigates the design of the structure itself. Second, these prior studies treat division managers' processing power to be endogenously designed by the firm to enhance innovation. In contrast, the current paper treats the task structure and managers' processing power as exogenous.

[3]Note that this definition of hierarchy is different than a simple count of layers within an organization structure. It is intended to capture firms' aggregated coordination responsibility above the lowest level.

[4]To illustrate, for the structure in Figure 2(c), divisionalization $= \log(4)$ (the same as in 2(b)), and hierarchy $= \log(1 \cdot 3 + 2 \cdot 2) = \log(7)$.

[5]The few prior studies that measure interrelationships between two business segments using the IO tables chose either 1% (Lemelin 1982) or 5% (Villalonga 2004) as the threshold.

[6]By construction, task complexity may be highly correlated with firm scope. This is because task complexity is the number of segment pairs that are interdependent with each other (links), whereas the maximum number of links is $N(N-1)$, N being the number of segments and the measure of firm scope. The greater the N, the greater will be the number of potential links between the segments. However, there are several reasons why the high correlation between task complexity and firm scope may not be a serious problem in this particular study. First, all my regressions use fixed effects models, so it is the collinearity between the time-demeaned variables, rather than the variables themselves, that should be of concern. The correlation between the time-demeaned task complexity and firm scope is 0.70, much smaller than the correlation between the variables themselves. Second, a variance inflation factor (VIF) analysis of the regressions returns VIFs close to 2, much lower than the critical values for concern (5–10). A collinearity test returns a condition number of 2.5, much lower than the critical values of 15–30. These tests further indicate that there is no significant collinearity (Neter et al. 2004). Using $N(N-1)$ instead of N as a control variable generates similar coefficients.

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Yue Maggie Zhou is an assistant professor at the Robert H. Smith School of Business, University of Maryland. She received her Ph.D. from the University of Michigan. Her research interests include theory of the firm, coordination, organization structure, and multinational corporations.