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Where do transactions come from? Modularity, transactions, and the boundaries of firms

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This article constructs a theory of the location of transactions and the boundaries of firms in a productive system. It proposes that systems of production can be viewed as networks, in which tasks-cum-agents are the nodes and transfers—of material, energy and information—between tasks and agents are the links. Transactions are defined as mutually agreed-upon transfers with compensation and are located *within* the task network. Placing a transaction in a particular location in turn requires work to define, count (or measure), and pay for the transacted objects. The costs of this work (labeled mundane transaction costs) are generally low at the thin crossing points of the task network, which correspond to module boundaries. Therefore, transactions are more likely to be located at module boundaries than in their interiors. Several implications arise from this theory. Among these: *Modularizations* create new module boundaries, hence new transaction locations. Areas in the task network where transfers are dense and complex should be located in *transaction-free zones*, so that the cost of transacting does not overburden the system. The thin crossing points between transaction-free zones constitute *breakpoints*, where firms and industries may split apart.

1. Introduction

For the last 30 years, economists have used the concepts of "transaction," "transaction cost," and "contract," to illuminate a wide range of phenomena, including vertical integration, contract design, the allocation of property rights, and the structure of industries. These concepts are now deeply embedded in the fields of economics, sociology, business, and law. But although economists and management scholars have explored the design of transactions in a wide variety of settings, in most of this literature, it is assumed that a pre-existing division of knowledge and effort makes a transaction possible at a particular place in the larger productive system. The theories explain how to choose between different forms of transactional governance, but they almost never ask why the opportunity to have a transaction occurs where it does. As a result, the forces driving the location of transactions in a system of production remain largely unexplored.

The goal of this article is to explain the location of transactions (and contracts) in a system of production. To do this, the article brings together three strands of literature—transaction cost economics and contract theory, knowledge-based theories of the firm, and modularity theory. Building on this work, I construct a theory of the location of transactions and the boundaries of firms by observing systems of production at a deeper level. Not surprisingly, the results obtained at this new level of observation are wholly consistent with prior theories of the firm. However, as is common in science, there are also new constructs and unifying principles that can only be seen by taking a deeper view of the phenomenon (Wilson, 1998).

First, drawing on modularity theory, I look at systems of production as networks, in which tasks-cum-agents are the nodes and transfers—of material, energy and information—between tasks and agents are the links. At this new level of observation, transactions are *not* primitive units of analysis as they were for Commons (1934) and Williamson (1985). Transactions, defined as mutually agreed-upon transfers with compensation, are located *within* the task network and serve to divide one set of tasks from another. Local properties of this network, specifically its modularity, make transactions more or less costly in different locations. In particular, *thin crossing points* at the boundaries of modules have low transaction costs, while *thick crossing points* in the interior of modules have high-transaction costs.

Transactions are designed to match their locations. In a given location, the objects being transacted must be defined and counted (or otherwise measured), and the purchaser must compensate the supplier. Thus, work goes into making the transaction. I call the costs of this work *mundane transaction costs* to distinguish them from the *opportunistic transaction costs* that are the focus of analysis by Williamson (1985, 1991) and the contract theorists (Grossman and Hart, 1986; Hart and Moore, 1990; Holmstrom and Milgrom, 1994). Expenditures on mundane transaction costs, I will argue, can reduce opportunistic transaction costs. Thus, to arrive at the optimal form of a transaction in a particular location, designers must make tradeoffs between the two types of cost, taking into account the local modular structure of the task network, i.e., the thickness of the crossing point in question.

The modular structure of the task network is not completely fixed, however. *Modularizations* create new thin crossing points where transaction costs are low. These new module boundaries provide points of entry for competitors and *breakpoints*, where vertically integrated firms and industries may split apart. Therefore, transaction locations are not technologically determined, but arise through the interplay of firms' strategies and knowledge and the requirements of specific technologies. Strategies, knowledge, and technologies all change over time, hence the location of transactions changes as well.

There are areas in the task network where transfers are dense and complex and not subject to modularization. In general, it is not cost-effective to place transactions in these locations: in terms of Coase (1937), the cost of "using the market" is too high. These areas, I will argue, should be located in *transaction-free zones* so that the cost of transacting does not overburden the productive system. Transactions can be used to move valuable goods into and out of transaction-free zones. Some transaction-free zones may be completely surrounded by transactions and thus encapsulated, creating the legal form of a modern corporation. Others zones may be unencapsulated, as is the case for many online and open source communities.

The theoretical arguments in this article support the following empirical predictions:

1. Transactions are more likely to be found at module boundaries than in module interiors.
2. The design of transactions differs systematically with the thickness of the crossing point. Spot transactions are more likely at thin crossing points, and formal and relational contracts at thicker ones.
3. The advantages of formal and relational contracts over spot transactions and of relational contracts over purely formal contracts increase with the thickness of the crossing point.
4. Transactors can sometimes modularize a naturally thick crossing point to reduce transaction costs. Transactional modularization is most likely to occur when the transactors cannot achieve a satisfactory relational contract.
5. In the aftermath of a modularization, entry and competition will arise at the new module boundaries. Conversely, when task networks are integrated and crossing points made thicker, firms that only make modules will lose their points of connection to the task network and be forced to exit.
6. Transaction-free zones are needed to facilitate complex, interdependent, and iterative transfers in the task network. Zones that produce rival goods or require large amounts of indivisible capital will be transactionally encapsulated, taking the legal form of modern corporations. Those that produce nonrival goods using low levels of capital can succeed as open zones without well-defined transactional boundaries.

Proposition 1 is a theoretically supported version of the classic mirroring hypothesis of modularity theory (Henderson and Clark, 1990; Sanchez and Mahoney, 1996). Propositions 2 and 3 adapt Williamson's discrimating alignment hypothesis (Williamson, 1991) to the task network level of observation. Proposition 4 supplies another reason to modularize beyond the traditional engineering rationales of managing complexity, allowing parallel work, and creating options. Proposition 5 predicts how industry structure will change in response to changes in the modular structure of the task network. Proposition 6 predicts the institutional form of transaction-free zones based on the goods produced and the underlying technology.

The rest of the article is organized as follows. In Section 2, I review the three literatures on which my theoretical arguments are built. In Section 3, I introduce the task network level of analysis and define transactions as they appear in the network. In Sections 4 and 5, I present the main theoretical arguments. In Section 6, I define *modularizations*, describing how and why they occur and how they affect transaction costs. In Section 7, I define *transaction-free zones*, and explain how they can be *encapsulated* by transactions and when this makes sense. In Section 8, I conclude by discussing the contributions and limitations of the analysis.

2. Literature review

In this section, I briefly review three strands of literature: (i) transaction cost economics and imperfect contract theory; (ii) knowledge-based theories of the firm; and (iii) modularity theory. Each looks at transactions and firm boundaries in a different way.

2.1 Transaction cost economics and imperfect contract theories

The assumption of static technology is hardwired into transaction cost economics and imperfect contract theories. To break its grip, systems of production must be represented in a new way.

The literature on transaction costs and the theory of the firm originates with Coase (1937). He observed that there were costs of using the market, and that “firms will emerge to organize what would otherwise be market transactions when their costs were less than the costs of carrying out the transactions through the market” (Coase, 1988: 7). Coase quite consistently defined transaction costs as the “cost of using the price mechanism” or “the costs of market transactions,” but he was also the first to assert that transactions occur within firms. In defining transactions this way, Coase made an important point that the stages of a production process can be designed to take place within one firm or across several firms. But he also implicitly assumed that a production process involves (only) a simple sequence of stages. In fact, Coase’s view was based on the paradigm of mass production, which envisioned organizations in terms of simple flow lines of material goods (Chandler, 1977; Abernathy *et al.*, 1983; Hounshell, 1985).

Despite later work which looked at complex flows of information in firms and task interdependencies in a more sophisticated way (March and Simon, 1958), the “sequence of stages” model of production still lies at the heart of transaction cost economics and contract theory today.

In contrast to Coase, who considered many types of transaction costs, Williamson (1985) focused on the harm that transactors can do to one another.

Williamsonian transaction costs are the measure of such harm. But though he changed the definition of transaction costs, Williamson adopted Coase's sequential view of production and continued the practice of treating all transfers, both within and across firms, as transactions. Formally, he defined a transaction as "a transfer across a technologically separable interface" (Williamson, 1985: 1). Notably, he did *not* define "technologically separable interface," but simply asserted that such places were fairly common in most systems of production. He did admit that there were places where "successive stages in the core technology should be under unified ownership" (p. 105). But such "mundane vertical integration" did not need to be explained: "The common ownership of some stations—the core—is sufficiently obvious that a careful comparative assessment is unneeded" (p. 98). However, with changing technology, what is in the core at one time can be split off at another (Tushman and Murmann, 1998; Murmann and Frenken, 2006). (We will see an example of this in Section 6.) Williamson's theory, which takes the core and interfaces of a technology as given, is blind to such changes, even though they will perforce change the location of transactions.

The imperfect contract or property rights theorists, including Grossman and Hart (1986), Hart and Moore (1990), and Baker *et al.* (2002) also modeled production as a sequence of stages and considered transfers between stages to be potential transactions. This strategy made the theories crisp and elegant, but it also limited their scope. Because of the way they model production, transaction cost economics and imperfect contract theory cannot formally encompass technological innovations that change the structure of a productive system. Williamson himself alluded to this limitation, saying "we need to find ways to treat technical and organizational innovation in a combined manner" (Williamson, 2000: 600). But, in fact, as mentioned earlier, the assumption of static technology is hardwired into these theories.

2.2 Knowledge-based theories of the firm

Knowledge-based theories of the firm incorporate the idea of shifting boundaries in ways that transaction cost economics and imperfect contract theory do not. However, these theories are not capable of determining the location of transactions, nor of predicting how the locations will shift in response to new knowledge.

Knowledge-based theories of the firm are diverse, but have in common that: (i) they focus on what goes on inside of a firm or organization; (ii) they agree that value (or "advantage") derives from things that a firm can do—these may be routines, competencies, or capabilities—that are not easily imitated or purchased; (iii) they recognize that routines, competencies or capabilities are based on knowledge, which is distributed across individuals and must be assembled and reconfigured in various ways. A brief sampling of this literature includes Nelson and Winter (1982), Demsetz (1988), Hayes *et al.* (1988), Pavitt (1991), Leonard-Barton (1992), Kogut and Zander (1992, 1996), Grant (1996), Conner and Prahalad (1996), Teece *et al.* (1997), Dosi *et al.* (2000), Nickerson and Zenger (2004), Marengo and Dosi (2005), and Jacobides and Winter (2005).

Changing routines, competencies, or capabilities based on knowledge must cause firms to have shifting *knowledge boundaries*. The span or scope of knowledge available to a firm will change over time as required by its changing activities. However, theories based on knowledge cannot directly explain the location of transactions.

The domain of transactions is a domain of action: goods are made; services are performed; compensation is paid and received. But research has shown that a firm's knowledge is generally not coterminous with its actions. Recent studies by Brusoni *et al.* (2001), Brusoni and Prencipe (2001), Sako (2004), Staudenmayer *et al.* (2005), and Ethiraj (2007) have demonstrated quite conclusively that firms generally "know more than they do." Therefore, a theory about the boundaries of a firm's knowledge cannot at the same time be a theory of the location of transactions for that firm. The two boundaries are related, but they are not the same.

2.3 Modularity theory

The gap in knowledge-based theories can be addressed by modularity theory, which focuses directly on actions and their dependencies. Modularity theory is rooted in the design theories of Herbert Simon (1962, 1969) and Christopher Alexander (1964). The modern literature can be traced back to three seminal contributions: (i) a paper on product architecture by Henderson and Clark (1990); (ii) a paper on task partitioning by von Hippel (1990); and (iii) a paper on the innovative potential of industries based on modular products by Langlois and Robertson (1992).

A key element of these and all subsequent papers in the modularity literature was a principle called the "mirroring hypothesis." Henderson and Clark (1990) applied the concept of mirroring to product development groups: "We have assumed that organizations are boundedly rational, and hence that *their knowledge and information processing structure come to mirror the internal structure of the product* they are designing" (p. 27, emphasis added). Sanchez and Mahoney (1996) expanded this concept to encompass whole firms.[1]

The mirroring hypothesis specifically links an organization's task structure to the actions of making and selling specific products. It implies that one can "see" the transactional boundaries of a firm by looking at its product and process designs—indeed, technically, the firm's transactional boundaries are subsumed in those designs (Fine and Whitney, 1996; Fine, 1998). Thus, as product and process designs change, so will transactional boundaries.

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[1] Colfer (2007) describes the theoretical underpinnings of the mirroring hypothesis and reviews the evidence for and against it.

2.4 The three strands come together

Although they invoked the mirroring hypothesis, early modularity theorists had little to say about the location or form of transactions. Langlois (2002, 2003) was the exception, and thus was in the vanguard of those who used modularity to explain changing industry structure. He first proposed that the economy was "modularized by property rights" and that the organizations were "demodularizations" in response to a need for interaction in the underlying technological processes (Langlois, 2002). He then challenged the thesis of Chandler (1977) that managerial hierarchies were necessary to coordinate large-scale productive systems. *Contra* Chandler, Langlois argued that in the late 20th century, modular product and process architectures made hierarchical coordination unnecessary in many venues. As a result, Chandler's "visible hand" was "vanishing," and firms that had previously been vertically integrated were splitting apart (Langlois, 2003).

Baldwin and Clark (2000) formalized and operationalized the foundations of modularity theory using a network representation tool from design theory called the Design Structure Matrix (Eppinger, 1991). Building on the theory of Holland (1992) of evolution in complex systems, they then constructed a theory of design evolution via "modular operators." This theory explained how new knowledge, incorporated into new designs, could change the modular structure of actual products and processes. But Baldwin and Clark were unable to derive a strong version of the mirroring hypothesis from their theory of design evolution. Applying their theory to the computer industry, they were forced to conclude that changes in the modular structure of computers were *necessary but not sufficient* to explain the changing vertical structure of that industry (Baldwin and Clark, 2000: 373–375).

Independently, Marengo *et al.* (2003) observed that economic theory had at its core "an implicit theory of modularity," in which tasks and problems are perfectly divisible. Marengo and Dosi (2005) went on to criticize transaction cost economics for ignoring task interdependencies and failing to account for historical patterns of industry evolution. They, together with Ethiraj and Levinthal (2004) and Rivkin and Siggelkow (2007), then investigated the impact of different modular decompositions on simulated searches in so-called "rugged landscapes." By considering the implications of interdependencies for vertical integration/disintegration, these works deepened the theoretical linkages between modularity theory and transaction cost economics. And because they viewed organizations essentially as problem-solving entities, they also brought modularity theory into the realm of knowledge-based theories of the firm.

These formal models and experiments were complemented by a growing body of empirical research and grounded theory-building focused on the vertical structure of industries. Sturgeon (2002) described the emergence of "modular production networks" in the US electronics industry and argued that this new organizational form would replace vertically integrated corporations in some settings.

Hoetker (2006) tested the mirroring hypothesis in an industry with rapid product innovation (notebook computers). His results were mixed: he found that product modularity was positively correlated with supplier turnover, but not with the decision to outsource. Importantly, he used both transaction cost economics and knowledge-based theories of the firm to derive his key propositions. Contemporaneously, Jacobides (2005) observed and theorized about the causes of vertical separation in an industry (mortgage banking), which, unlike computers, was not subject to dramatic changes in product designs. Jacobides and Billinger (2006) went on to observe the process of vertical *separation* within a single firm, while Cacciatori and Jacobides (2005) documented the *integration* of an industry (construction). Finally, Fixson and Park (forthcoming) documented a theoretically interesting case in which an industry (bicycle drive trains) integrated *and* consolidated as a result of a single firm's change in its product architecture. As a group, these studies showed in detail: (i) how organizational processes change with the introduction of new product and process architectures and (ii) how the new architectures then give rise to new markets and new industries.

Taken as a whole, modularity theory and related empirical research suggest a new level of observation for studies of the boundaries of firms. In modularity theory, the basic unit of analysis is not a "stage" in a sequential production process, nor is it "knowledge" that contributes to a routine, a competency, or a capability. Instead the primitive units of analysis are decisions, components, or tasks, and their dependencies. Decisions, components, and tasks are more microscopic than stages, but more concrete and directly observable than knowledge. And the dependencies between decisions, components, or tasks can be represented in terms of a network as described in the next section.

At the deeper level of analysis suggested by modularity theory, the job of transaction design changes. It is no longer enough to choose a form of governance at a prespecified location between two stages of production. The larger task involves: (i) locating transactions in the task network; (ii) designing each transaction to suit the task network's local structure; and, often, (iii) modifying the network's structure to better accommodate the transaction. I address these issues in Sections 4–6 subsequently.

3. Definitions

This section lays the groundwork of my theory in the form of a set of basic definitions.

3.1 The task network

The basic unit in the design of any production process is a *task* (Galbraith, 1977; Tushman and Nadler, 1978; Marengo and Dosi, 2005). Tasks must be carried out by agents, but, because of physical and cognitive limitations, no single agent is capable of carrying out all tasks (March and Simon, 1958). Thus, it is necessary to *transfer* various things—material, energy and information—from agent to agent in a productive system. Taken as a whole, the tasks, the agents, and the transfers make up a vast *network* of activity, in which tasks-cum-agents are the nodes and transfers are the links. I call this the "task network" or simply "the network" for short. In a well-functioning task network, agents perform the tasks (including design tasks) needed to produce goods and services. Agents are also matched to tasks and are linked via transfers in such a way that the desired goods are obtained, and no agent has to carry out tasks beyond his or her ability.

As indicated, the network model of production is more microscopic than the "sequence of stages" model of Coase (1937), Williamson (1985), and the contract theorists (Grossman and Hart, 1986; Hart and Moore, 1990; Baker *et al.*, 2002). It also takes a more modern view of organizations. Scholars including March and Simon (1958), Thompson (1967), Lawrence and Lorsch (1967), Weick (1969), Galbraith (1977), and Tushman and Nadler (1978) have called attention to the microstructure of tasks in organizations, and especially to dependencies among decisions and tasks. The task network model seeks to capture these dependencies as an "activity system" in terms of nodes and links. This practice was pioneered by Porter (1996) and has been utilized by Rivkin (2000), Siggelkow (2001), Ethiraj and Levinthal (2004), and Rivkin and Siggelkow (2007).[2]

On the one hand, one can think of the task network representation as a way of "zooming in" on the sequence of stages in prior models in order to see what is going on in more detail. At the same time, representing production as a network of tasks allows us to model new patterns of dependency and interaction, including parallel flows of material and information, backward flows (feedback), and iterative and uncertain flows (trial-and-error). These more complex patterns cannot be modeled as a simple "sequence of stages," but they do arise—frequently—in real production processes.

The tasks and transfers in the network are designed (Simon, 1969), but *not* by a single person. The designers of the network are people with local knowledge, local authority, local property rights, and local incentives (Hayek, 1945). Because of intrinsic cognitive limits—what Simon (1969) called "bounded rationality"—a single individual, team or company can only work on a subset of the network and on interfaces between subsets. Transactions, we will see, are a way to create efficient interfaces between subsets of tasks.

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[2] Others, e.g., Langlois and Robertson (1992), Powell (1987), and Sturgeon (2002), have modeled production as a network of *firms*, but not as a network of *tasks*. There has also been a great deal of work on alliance networks, e.g., Gulati (1998); reputation networks, e.g., Stuart (1998); and knowledge networks, e.g., Murmann (2003) and Fleming *et al.* (2006). These constructs are all distinct from the task network.

3.2 Transactions

I define a *transaction* to be a mutually agreed-upon set of transfers between two or more parties with compensatory payment. This definition breaks with tradition: what I call a transaction is what Coase sometimes called an "exchange transaction" in contrast to "internal transactions" that take place within firms (Coase, 1937: 393–398).

As indicated, in comparison to Coase, Williamson, and the contract theorists, I model production as it is seen closer up—as a network of *many* complex transfers. At this new, more microscopic level of observation, transactions are *not* the "basic unit of analysis" (Commons, 1934, cited by Williamson, 1985: 3), but are instead embedded in a more complex network structure. On this view, a transaction (or "exchange transaction" in Coase's terminology) is more than a simple transfer. It is a reciprocal exchange based on some degree of mutual understanding.

3.3 Mundane transaction costs

To be the basis of a reciprocal exchange, a transfer (or set of transfers) must be (i) defined; (ii) counted (or measured); and (iii) compensated. Definition, counting and compensation are needed to create the "common ground" on which transactors establish a mutually agreeable exchange (Clark, 1996). But creating this common ground involves work: it adds new tasks to the network. Thus, a transaction is a transfer (or set of transfers) embellished with several added and costly features. I call these costs the "mundane transactions costs" of the transaction to distinguish them from the "opportunistic transaction costs" of Williamson and the contract theorists. My theory of the location of transactions is based on the argument that mundane transaction costs are low in some places in the task network and high in others.

Definition provides a description of the object(s) being transferred. It places the objects of the transaction into a defined category that is recognized by both parties. Defining adds the costs of describing, communicating, and (sometimes) negotiating to the system. In contract theory, if both parties agree on the definition of what is transferred ("this is indeed a satisfactory widget"), the transfer is called "observable." If third parties can be brought in and also agree ("anyone can see this is a satisfactory widget"), the transfer is "verifiable." These implicit costs of observing and verifying are mundane transaction costs under my definition. Contract theorists maintain that such costs are the underlying cause of contractual incompleteness, but treat them as axiomatic, hence outside their theory (cf. Hart, 1995: 23–24).

Counting associates with the transferred object a quantity—a number, weight, volume, length of time, or flow. Definition is a prerequisite to counting, because one can only count or measure objects within a class or category. Economics generally takes the existence of these predefined categories to be axiomatic. In other words, goods are defined outside of economics, while prices and quantities (i.e., counts) are determined inside of economics.[3]

When I say that transacted goods must be "counted," I do not mean to imply that transactions always involve aggregations of goods, like bushels of wheat or tons of steel. Unique goods can be transacted—their count is simply "one." My definition of "counting" also subsumes all measuring processes that are used to verify the quality of the transacted object. For example, a complex good, such as a chemical plant, is a unique item (Brusoni and Prencipe, 2001). But the contract between the buyer and supplier of the plant will contain pages of detailed conditions, all of which must be met before the transaction is complete. These conditions define the transacted good. Verifying the conditions involves measurement, hence is a mundane transaction cost of counting.

Finally, *compensation* involves the backward transfer of "consideration," from the recipient to the provider of the transacted object. This in turn requires systems for valuing the object and paying for it. Modern market economies have highly efficient institutions and bodies of knowledge in each of these domains. But whatever the form of compensation, for a transaction to take place, two valuations must occur (one by the buyer and one by the seller), and a payment must be made. The costs of these valuations and payments are mundane transaction costs of compensation.

Transactions are designed, and thus mundane transaction costs are not exogenously determined. The transactors must decide how much to spend on definition, counting, and compensation. Definitions can be precise, running to hundreds of pages as in the chemical plant example, or vague as in "consulting services." Counting and compensation can also be precise or approximate. In general higher levels of precision are more costly, thus transaction designers must make judgments as to how much precision is needed in a particular setting. (Transaction design is treated in Section 5 subsequently.)

4. The determinants of mundane transaction costs in the task network

As indicated, part of the job of designing a task network is to *locate* the transactions among the tasks. In this section, I argue that mundane transaction costs are low at the boundaries of modules and high in their interiors. Thus, given a choice between placing a transaction at the boundary or in the interior of a module, one should always choose the boundary. However, to understand the relationship between module boundaries and mundane transaction costs, we must look at the task network itself in more detail. For this purpose, I introduce two concepts from modularity theory: *information hiding* and *thin crossing points.*

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[3] Barzel (1997) is a notable exception, however, as he conceives of goods as fluctuating bundles of attributes and property rights.

4.1 Information hiding, thin crossing points, and modularity

An economical transfer of a good from its producer to a user constrains the surrounding transfers of information quite dramatically. The user cannot know everything about how the thing was made: if that information were necessary, the user would have to produce the thing himself, or at least watch every step of production. The efficiency of the division of labor would then collapse. By the same token, the producer cannot know everything about how the thing will be used, for then she would have to be the user, or watch the user's every action. Thus, fundamental to the efficient division of labor is substantial *information hiding* (Parnas, 1972). This information hiding in turn supports what Aoki (2001: 96) calls the "division of cognitive labor." The user and the producer need to be deeply knowledgeable in their own domains, but each needs only a little knowledge about the others'. This is in fact the core assumption of the knowledge-based view of the firm.

If labor is divided between two domains and most task-relevant information hidden within each one, then only a few, relatively simple transfers of material, energy and information need to pass between the domains. The overall network will then have a *thin crossing point* at the juncture of the two subnetworks.

In modularity theory, a module is a group of elements—in this case, tasks—that are highly interdependent on one another, but only minimally dependent on what happens in other modules (Baldwin and Clark, 2000: 63). By definition, modules are separated from one another by thin crossing points—in Simon's (1962) terminology, they are "near decomposable."

Mundane transaction costs are the costs of defining, counting, and paying for things transferred. At thin crossing points between modules, there are, by definition, fewer and simpler transfers than within modules. Mundane transaction costs will be thus low at thin crossing points. *It follows that transactions are best located at thin crossing points, i.e., at the boundaries of modules, not in their interiors.*

4.2 An example: the production and use of an iron pot hook

To make this argument concrete, let us look at the production and use of an iron pot hook in medieval times. (I chose this example because it involves team production, but is relatively simple compared to most modern task networks.) Working with iron requires a division of labor: there are many tasks that must be carried out simultaneously, in order for the metallurgical processes to work. In medieval times, the efficient production of iron artifacts required from two to six people. The same was true of cooking.

Assume there are five people on the smith's team <S1, . . . , S5>, and five on the cook's team <C1, . . . , C5>. If we were to drop into the smith's establishment and record all transfers of material, energy, and information, the resulting graph would be bi-directional and complete. Every member of the smith's team, no matter how lowly, would at some point give material, energy, or information to every other

			Smithy					Kitchen				
		CG	S1	S2	S3	S4	S5	K1	K2	K3	K4	K5
	CG	.										
	S1	x	.	x	x	x	x					
Smithy	S2	x	x	.	x	x	x					
	S3	x	x	x	.	x	x					
	S4	x	x	x	x	.	x					
	S5	x	x	x	x	x	.					
	K1	x			**Pot Hook**		x	.	x	x	x	x
Kitchen	K2	x			**Transfer**			x	.	x	x	x
	K3	x						x	x	.	x	x
	K4	x						x	x	x	.	x
	K5	x						x	x	x	x	.

Figure 1 Task structure dependency matrix for a smithy and a kitchen.

member, and each would receive material, energy or information from every other. The same would be true of the kitchen team. Pot hooks and other iron implements form a bridge between the two establishments.

We can represent the task network of the smithy and the kitchen using a task structure dependency matrix (Simon, 1962; Eppinger, 1991; Baldwin and Clark, 2000; Ethiraj and Levinthal, 2004; Rivkin and Sigglekow, 2007). First, we list the members of each team along the rows and columns of a square matrix. Then, if agent *i* transfers material, energy, or information to agent *j*, we place an "**x**" in the column of *i* and the row of *j*. The results are shown in Figure 1. The dense transfers of material, energy and information *within* the smithy and the kitchen show up as blocks of "**x**'s" in the task structure matrix. But between the two establishments, there is only one point of interaction: the transfer of a completed implement, the pot hook.

The matrix shows that, in terms of tasks, the smithy and the kitchen are almost, but not quite, independent. The two establishments are *materially connected* by pot hooks and other iron implements, which are made in the smithy and used in a kitchen. And they are *informationally connected* by a set of common definitions of pot hooks and other iron implements. In the language of modularity theory, the common definitions serve as design rules, and, by convention, they appear as a vertical column on the left hand side of the matrix (Baldwin and Clark, 2000). The design rules are the "common ground" of the two establishments, thus we have labeled them "CG." (Clark, 1996; Srikanth and Puranam, 2006). Given this common ground, the two establishments can support one another without a lot of ongoing interaction. Hence, this particular pair of subnetworks displays almost perfect information hiding.

It is also relatively easy to turn the completed pot hook transfer into a transaction. Because of their common ground, a smith and a cook both know what a pot hook is, and can agree on its salient features (size, thickness, shape). In this fashion, the object being transferred is easily defined. Pots hooks are discrete material objects, thus easy to count. And cooks know what to do with completed pot hooks: they can easily value them and know what they are willing to pay. Defining, counting, and paying for the pot hook adds a few more tasks to the network, but not many. Thus, the mundane transaction costs at this location are relatively low.

As predicted, the completed pot hook transfer point appears as a *thin crossing point* in the task network: the narrow point between two densely connected subnetworks. This means that while there are many complex transfers of material, energy and information that need to take place within each establishment, there are only a few, relatively simple transfers that need to take place between them. Pushing the transaction backward into the smith's establishment or forward into the kitchen would require more complex methods of defining, counting, and paying for what was being transacted. Thus, if the transaction were located at any other transfer point in the two processes (and there are hundreds of transfers points within each), the mundane costs of the transaction and the knowledge overlap between the two establishments would go up. Higher mundane transaction costs and more knowledge overlap result in a less attractive transaction location.

Knowledge-based theories of the firm argue that firms exist to economize on the production and exchange of knowledge. It follows immediately that the boundaries of firms should be placed so as to minimize knowledge overlaps between firms. Hence, the recommended location of the pot hook transaction derived from modularity theory is consistent with knowledge-based theories of the firm. However, knowledge-based theories do not address the question of where to locate transactions when there is a large amount of knowledge overlap. The concepts of task independence and information hiding from modularity theory, plus the concept of mundane transaction costs, can be used to answer this question.

For example, suppose the cooks knew everything about iron-making and the smiths knew how to cook. The knowledge sets of the two establishments would then be identical. But, I argue, the best place to locate a transaction is still at the thin crossing point between the two task modules. The reason is that, even with the same knowledge, the two establishments neither have identical real-time information nor identical interests. Each must be therefore concerned about opportunism by the other, including holdup, haggling, and disputes over who did what. Transacting based on an object that is well-defined and easily countable (or otherwise measurable) reduces the grounds for disagreement, thereby reducing Williamsonian transaction costs. It also makes the transaction more understandable to third parties, hence "more verifiable" in the language of contract theory.

In sum, locating transactions at thin crossing points between modules supports the division of knowledge between firms, consistent with knowledge-based theories of the firm. But even with *no* division of knowledge, thin crossing points, i.e., module boundaries, are still good places to locate transactions. It is a property of thin

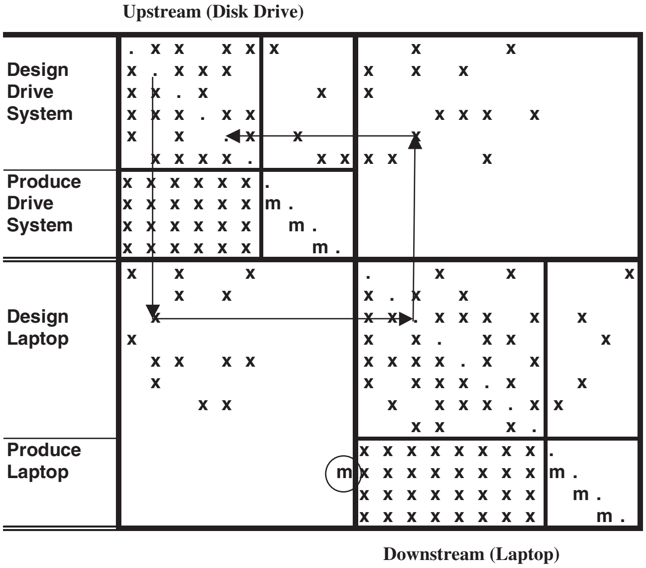

Figure 2 Stylized task structure dependency matrix for a laptop-disk drive productive system.

crossing points that mundane transaction costs are low at these locations, and *mundane transaction costs can be used to reduce opportunistic transaction costs.* The next section elaborates on this possibility.

5. The design of transactions: trading off mundane and opportunistic transaction costs

This section considers transactions that are located at *thick* crossing points in the task network, where the divisions of knowledge and effort are not as clean as between the smiths and the cooks. At a thick crossing point, I consider two extreme transaction designs, which are respectively “minimal” and “maximal” in terms of mundane transaction costs. I argue that neither design is likely to be optimal, but something in between might work.

5.1 An example: the design and production of a laptop with a disk drive

Consider two firms, called Upstream and Downstream. For concreteness, assume that Upstream designs and produces disk drives while Downstream designs and produces laptop computers. A simplified task structure matrix for this productive system is shown in Figure 2. It captures in a stylized way empirical work by Clark and Fujimoto (1991), Argyres (1999), Brusoni and Prencipe (2001), Mayer and Argyres (2004), Staudenmayer *et al.* (2005), Hoetker (2006), and Ethiraj (2007) that shows how firms today collaborate *in the design* of complex goods and services and then separately manufacture different components of the system.

In this matrix, transfers of design information are denoted by "**x**"s, and transfers of material by "**m**"s. The circled "**m**" near the bottom of the matrix denotes the transfer of a finished disk drive to the laptop assembly line. The cycle of arrows through "**x**"s depicts a process of trial-and-error problem solving: iterations like this are the hallmark of design processes (Eppinger, 1991; Baldwin and Clark, 2000). (The real task network for processes like these would have many more tasks, dependencies, and potential paths. The laptop and disk drive makers would also have common ground in the form of shared standards. To simplify the figure, I have shrunk the network, depicted only one path, and omitted the common ground.)

In contrast to the smiths and the cooks, the disk drive and laptop firms' task networks are highly interdependent *in their design processes.* As is typical today, manufacturing is a sequential process: the pattern of "**m**"s (material transfers) shows that disk drives will be made in Upstream's factories, delivered to Downstream, and then assembled into the laptops. But the pattern of "**x**"s indicates that there are many occasions when designers at one firm will require design information from the other. Moreover, design information transfers are complex: they are not simply instructions that trigger well-defined actions like the payment of a bill or the shipment of a book. Design information transfers, by definition, consist of questions whose answers are unknown and proposed solutions whose values are uncertain. They are relatively rich (Daft and Lengel, 1986), poorly specified (Puranam and Jacobides, 2006), and have uncertain and open-ended consequences (Baldwin and Clark, 2000). Yet, leaving out any of them may drastically reduce the value of the final good!

Does it make sense to place a transaction between the disk drive and the laptop firms? What would such a transaction look like?

5.2 The "*minimal*" transaction design

Consider first a "minimal" transaction design. Following the example of the smiths and the cooks, the disk drive and laptop firms could define, count, and pay for only finished disk drives. This design minimizes mundane transaction costs conditional on having a transaction at all. Unfortunately, it also makes the two firms vulnerable to holdup (Klein *et al.*, 1978; Williamson, 1985) and other opportunistic transaction costs.

For example, a minimal transaction design, by definition, contains no provisions, formal or informal, for compensation if one or the other party reneges. Yet, the task structure calls for the designs of the disk drive and the laptop to be interdependent. In design theory, if two designs are interdependent, each is specific to the other. Thus, design interdependency is a form of Williamsonian *asset specificity* (Williamson, 1985). As is well known, given asset specificity, once Upstream's costs are sunk, Downstream can unilaterally set a low price, causing Upstream to lose its investment. Or in another holdup scenario, if the demand for laptops is unexpectedly high, Upstream might demand a higher price in return for timely shipments. In the presence of these opportunistic threats, each party has reason to make defensive investments in the spirit of Grossman and Hart (1986) and Hart and Moore (1990). For example, the drive firm might spend money to make its drives compatible with other systems and the laptop firm might look for second-source suppliers. But such *ex ante* defensive actions reduce the value of the entire system, even if *ex post* bargaining is efficient.

The minimal transaction design also adversely affects incentives within Upstream. A productive system that is dense with dependencies by definition requires "multi-tasking" (Holmstrom and Milgrom, 1994; Baker, 2002). In other words, to produce a high-quality laptop, a great deal of design information needs to be "produced" and transferred between the two firms. But a minimal transaction only defines, counts and provides compensation for disk drives. Transfers of design information between the two firms (the "**x**"s in the off-diagonal blocks) are costly to the drive maker, but unrewarded. Thus, Upstream will skimp on these transfers as much as possible or shirk them altogether. Such skimping (or shirking) reduces the value of the end product, hurting both firms.

In short, a minimal transaction at a thick crossing point is a hotbed of opportunistic behavior. There is no direct compensation to either firm for transferring information, and there is no promise of a future relationship to provide indirect compensation. Self-interested agents will then skimp on information transfers; *ex post* holdups are likely; and defensive investments (on both sides) are rational and prudent.

Reducing opportunistic behavior in a transaction like this requires a contract, either formal or relational. A formal contract *defines* the responsibilities of each party; *measures* compliance; and establishes multi-dimensional *compensation*. Thus, a formal contract reduces opportunistic transaction costs by increasing mundane transaction costs.

Relational contracts also incur mundane transaction costs, but in less obvious ways. To control opportunistic behavior, a relational contract creates "a shadow of the future" and provides a means of *ex post* settling up to make the distribution of gains more fair (Baker *et al.*, 2002). But relational contracts don't just happen: like any form of contract, they must be designed and managed (Sako, 1992, 2004). Two strangers cannot immediately arrive at a relational contract: there are numerous tasks (e.g., meetings) and transfers (e.g., conversations) involved in *defining* the relationship. In addition, costs of *counting*, *valuation* and *payment* arise in the course of adjudicating *ex post* settlement. Showing how this works in practice, Mayer and Argyres (2004) describe how, over eleven contracting rounds, a PC company and a software company learned to define, measure, and provide informal compensation for more and more of their complex design information transfers. Trust between these two companies grew even as their contracts became lengthier.[4] In this fashion, mundane transaction costs—including the costs of setting up the initial open-ended relationship—reduced opportunistic transaction costs and improved the quality of the relational contract over time.

5.3 A "*maximal*" *transaction design*

At the opposite end of the spectrum from the minimal transaction is a "maximal" transaction design, in which the firms attempt to define, count, value, and pay for *every* transfer between them. Obviously, the maximal design involves higher mundane transactions costs than the minimal transaction, but, in principle, it might bring down opportunistic transaction costs enough to justify the added expense.

A maximal transaction design at a thick crossing point quickly runs into difficulties, however. At a thick crossing point (as opposed to a thin one) there are, by definition, many complex, uncertain, and iterative transfers—too many to realistically expect to define or count. Can two firms with interdependent designs really expect to define and count *all* necessary transfers of design information? Will *every* exchange of information be counted? How will each be valued?

When transfers of information are complex, uncertain, and iterative—as is always the case in design processes—the burden of defining, counting, and paying for transfers becomes overwhelming. Thus, a maximal transaction design weighs down the productive system with a lot of extra overhead. And (as if that were not enough) if design information transfers are counted and compensated, there is a risk—indeed a certainty—that unproductive transfers will take place, not because they add value but because they add or subtract "points" to a compensation scorecard (Kerr, 1975; Holmstrom and Milgrom, 1994; Baker, 2002). Thus with a maximal transaction design, information transfers will go from being skimped on to being overproduced.

5.4 Trading off mundane and opportunistic transaction costs

It seems that at a thick crossing point transaction designers are caught between a rock and a hard place. On the one hand, if they do *not* define, count, and pay for the necessary transfers, self-interested agents will skimp on them. But if they do try to define, count and pay for all transfers, they will burden the productive system with extra overhead and create perverse incentives to initiate more transfers than are needed. [This argument is close to the explanation by Hart (1995: 23–24) of why

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[4] Mayer and Argyres (2004) point out that this finding stands in contrast to other findings in laboratory settings, which show that trust diminishes in the presence of formal contracting (Malhotra and Murnighan, 2002). The resolution of this discrepancy may lie in the fact that experimental subjects perforce interact for only short periods of time, thus do not build up their relational contract over time. Formal contracts and trust may be substitutes in the short run when the parties are signaling their respective approaches, but complements in the longer run when the parties are learning to manage their ongoing relationship.

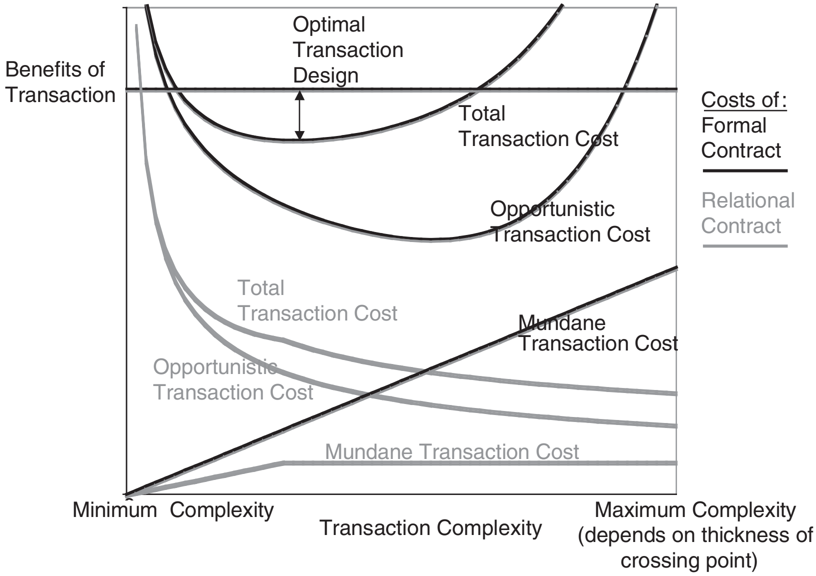

Figure 3 Finding the 'Optimal' transaction design.

contracts are necessarily incomplete. But, as indicated earlier, Hart treats contract incompleteness as axiomatic, while we are concerned with finding the "right degree" of incompleteness at a particular place in the task network.]

Does this mean that transactions should not be placed at thick crossing points? Both transaction cost economists and contract theorists suggest that internalizing transfers within a firm is sometimes the best solution to the transaction design problem. (This possibility is discussed in Section 7 subsequently.) But we can also think about designing transactions with varying levels of mundane transaction costs. Even if the minimal and maximal transactions do not work, there might be intermediate designs for which the benefits of having the transaction outweigh the costs.

Figure 3 illustrates how designers can trade off mundane and opportunistic transaction costs at a thick crossing point in the task network. The vertical axis denotes benefits and costs (in dollars). For the sake of argument, I assume there are benefits, in the form of gains from specialization (Jacobides and Winter, 2005) or extra effort (Hart, 1995; Baker *et al.*, 2002) to having the transaction. These are indicated by the horizontal line near the top of the figure.

The horizontal axis denotes transaction complexity: the more transfers that are defined, counted, and paid for in the contract, the more complex it is. Maximum complexity, denoted by the breadth of the horizontal axis, depends on the thickness of the crossing point. Thicker crossing points have *combinatorially* higher maximum complexity than thin crossing points because (i) there are more transfers to define, count, and pay for; (ii) many transfers of design information are unstructured, and each has uncertain and open-ended consequences; and (iii) in the presence of iteration and trial-and-error problem-solving, there are many more potential paths, i.e., sequences of transfers.

The black lines in the figure indicate the costs of *formal contracts* of varying complexity. Mundane transaction costs rise as a function of complexity and are indicated by a linear function. As more transfers are defined, counted, and paid for, however, opportunistic costs go down, until, at some point, perverse incentives set in. Thus, opportunistic transaction costs are a U-shaped function of complexity. Total transaction costs are the sum of the mundane and opportunistic transaction costs.

A transaction is worthwhile if its benefits exceed its total costs. In the figure, this occurs in the middle range of transaction complexity. A formal contract of intermediate complexity thus has positive value, but contracts with more or less complexity have negative value and should be avoided. In other words, the two firms would be better off vertically integrating (hence losing the benefits of having the transaction), rather than operating under a poor transaction design.

Introducing *relational contracts* changes the graph in two ways, as indicated by the gray lines in the figure. First, relational contracts are adaptive in the sense that many types of transfers will be counted and paid for ("settled") only if their cost deviates out of some normal band. The adaptiveness of relational contracts causes the mundane transaction cost line to flatten out at higher levels of complexity: the parties can achieve a more complex contract more cheaply in the context of an ongoing adaptive relationship. Second, the "shadow of the future" reduces opportunistic transaction costs, including incentives to "game" the contract. Hence the opportunistic transaction cost line is lower for all levels of complexity, and may flatten instead of curving upward. Total transaction costs (denoted by the highest gray line) are thus generally lower for relational contracts than formal contracts for all degrees of complexity. Net transaction benefits are correspondingly higher and thus relational contacts are generally to be preferred over purely formal contracts at thick crossing points. However, relationships are based on prior knowledge and trust; hence relational contracts are not always an option for transactors (Sako, 1992; Gulati, 1998).

To summarize, at thick crossing points in the task network, relational contracts dominate formal contracts of intermediate complexity, which in turn dominate minimal and maximal transaction designs. If possible, transactions at thick crossing points should be structured as relational contracts, and, failing that, as formal contracts of intermediate complexity. If those alternatives fail, the transfers should be internalized within a single firm.

6. Modularizing the network

Up to this point, I have assumed that the task network's structure is fixed. In this section, I consider the possibility of making a thick crossing point thinner through the process of *modularization*. We have seen that thinner crossing points have lower total transaction costs, thus firms wishing to transact may modularize their task networks to support the transaction. However, modularizations can also be undertaken for other reasons. *Regardless of their intended purpose*, modularizations create new module boundaries with low transaction costs. Competition at the new boundaries may ensue.

6.1 An example: the design of a plastic for use in an automobile

I begin by describing a modularization undertaken for the purpose of supporting a transaction. In 1994, an automobile manufacturer sought to find a new plastic for automobile interiors. Clark (1995) described the resultant transaction as follows:

> [T]he automotive customer developed "specifications" that the new material had to meet in order to qualify for and win the business. There were eight items in the specification, including heat resistance, cost, strength and so forth. *Each specification was accompanied by a testing protocol and a standard that the material had to meet.* (Clark, 1995, emphasis added)

The *natural* dependency structure between the plastic and the auto companies was very similar to that of the disk drive and laptop companies shown in Figure 2. That is, their manufacturing processes were quite separate, but their designs were highly interdependent. Many properties of the plastic (e.g., its weight, viscosity, and color) affected the automobile's design, but those same properties also affected the cost of making the plastic. Interdependencies in the design processes created a natural thick crossing point between the two parties.

As we have seen, the firms had several options for handling the thick crossing point. A minimal transaction design would have been problematic for the reasons described earlier. But they could have structured a formal contract or, if they trusted each other enough, worked out a relational contract. Or they might have vertically integrated.

Instead, the auto company took the lead and chose to modularize the task network. Baldwin and Clark (2000) describe the process of modularization as follows:

> [T]he architects . . . have as their goal the creation of a set of independent blocks at the core of the design process. They . . . then set about systematically to sever all dependencies known to exist across the proto-modules. . . . [I]nterdependencies can be severed by promulgating design rules early in the process. (p. 70)

The auto company modularized the task network in just this way. They figured out what the key dependencies were and then severed them by specifying how the plastic

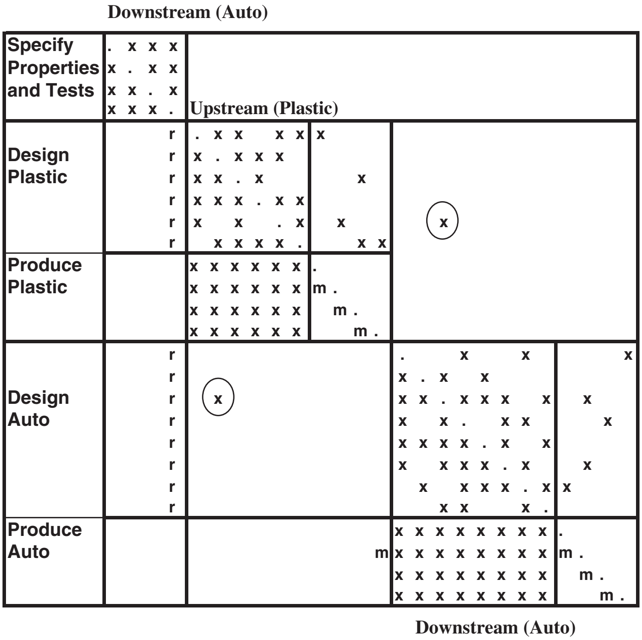

Figure 4 The modularized task dependency structure of the plastic-auto transaction.

would interface with the automobile on these dimensions. They also created eight tests to determine whether a particular plastic compound was satisfactory.

Figure 4 shows the resulting task structure. (Again, the real network was much larger than the one shown here.) The task structure is the same as the laptop and disk drive firms' (Figure 2), except that (i) most of the ongoing transfers of design information *between the two firms* have disappeared (only two "**x**"s remain in the off-diagonal blocks between Upstream and Downstream); and (ii) there are now design rules—a dense block of design information transfers in the upper left corner with a column of rule transfers (denoted by "**r**"s) below it.[5]

The dense block of transfers in the upper left denotes the specification phase of this transaction. In this phase, the auto company *defined* the object to be transacted and set up eight ways of *measuring* it. *Payments* to the plastic company were predicated on passing the tests. The specification phase thus established the common ground for the transaction (Clark, 1996) and provided design rules for the teams at

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[5] The communication of design rules is a transfer of information. However, unlike design information pertaining to problem-solving, design rules are—or should be—well-structured and concise, that is, neither unstructured nor rich. Thus, I use different symbols to denote rule transfers and design information transfers. The process of specifying design rules is a process of articulation and codification as defined by Hakanson (2007).

both companies, as indicated by the column of "**r**'s" below the specification block. (In this instance, the auto company used its market power to unilaterally define the design rules. In other cases, design rules are negotiated.)

In contrast to Figure 2, the task structure dependency matrix in Figure 4 has an obvious thin crossing point between Upstream and Downstream. The best place to locate the transaction between the two firms is clear. Indeed, the thin crossing point was created *for* this very purpose.

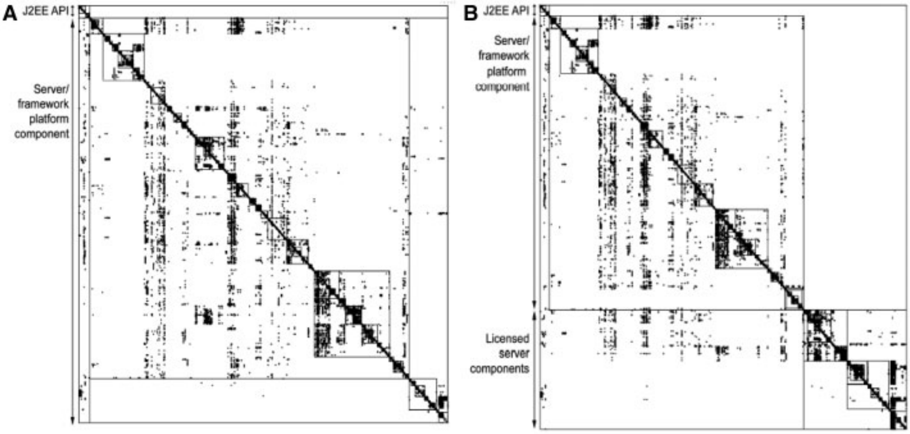
Modularizing the network involved work. The costs were those of *defining* the object to be transferred, *measuring* it, and arranging for *compensation*, i.e., they were mundane transaction costs. In this case, upfront mundane transaction costs were expended to create a thin crossing point, which served to reduce subsequent frictional and opportunistic transaction costs.

In general, however, it is impossible to say whether it is better to design a contract around a given "natural" set of dependencies or to modularize the dependencies using the method of design rules. Each approach involves different costs and benefits. Modularization, in particular, requires detailed prior knowledge of dependencies—knowledge that might not exist when the parties design their transaction. Thus while modularization is always an option, it is not always a good option.

In fact, the modularization of the plastic and auto design processes was not complete. A property of the plastic—"rich, lustrous appearance"—turned out to be critical to the auto company, but at the same time, the auto company's designers could not define it, measure it, or test for it. This property became the focus of trial-and-error search *across* the two companies. Many samples and related technical information were transferred back and forth as the two companies worked to find a solution to this design problem (Clark, 1995). In the task structure matrix, the existence of those unresolved dependencies and the need for ongoing tranfers are indicated by the two circled "**x**"s in the off-diagonal blocks between Upstream and Downstream. The presence of these "**x**"s means that the two design processes were *near-decomposable* by Simon's (1962) definition, but not *perfectly modular* by Baldwin and Clark's (2000) definition.

As it happens, the transfers of material and information related to the rich, lustrous appearance issue were neither counted nor paid for. When the issue emerged, the two firms could have amended their formal contract to include definitions, measures, and compensation for "work to obtain a rich, lustrous appearance." However, they chose not to do this, but instead allowed this portion of their work to be subsumed in their ongoing relational contract.

Indeed, the literature on transaction design is full of examples of partial modularizations. In these instances, crossing points in the task network are made thinner, but still remain quite thick. For example, transactors often set up "single points of contact" or "liaisons" through which requests for information and change orders must pass (cf. Sako, 2004; Mayer and Argyres, 2004; Staudenmayer *et al.*, 2005).



Source: LaMantia *et. al.* (2008). Reproduced by permission.

Figure 5 Design structure matrix of platform and licensed code before and after modularization. (**A**) Before modularization: licensed components are spread throughout the platform. (**B**) After modularization: licensed components are relegated to separate module. The platform does not depend on the licensed components

By requiring that information flow through a single individual or department, these provisions *ipso facto* create thinner crossing points between two organizations.

However, in the absence of a relational contract, more radical forms of modularization may be deemed necessary. LaMantia *et al.* (2007) describe a theoretically interesting case in which a software company licensed components from another company and used them in its platform, i.e., the shared code on which all its products depended. The two companies did not have a relational contract, and thus, when the license was due to expire, the licensor "could prohibit [the company] from releasing new versions of its software . . . [or] . . . raise the price of the license (p. 6). In response to this perceived threat, the company assembled a team of software engineers and charged them with redesigning the platform to reduce the transactional hazard.

Figure 5 shows the design structure matrices for the platform before and after the redesign. These graphs depict in matrix form the task networks of two software programs. (Unlike the stylized task networks above, these are a complete task networks for the software in question.) The rows and columns (nodes) represent software components and the off-diagonal entries (links) indicate transfers of information between components as when one component "calls" or "uses" another. Licensed components belong to the licensor and effectively are lent to the licensee for the term of the license. Thus incorporating licensed components into a codebase is like subcontracting out parts of a production system to "guest workers" from another firm.

As shown in panel A, before the redesign, the licensed components were spread throughout the platform. After the redesign (panel B), those same components were segregated in a separate module. There is a clear boundary—a thin crossing point—between the new platform and the licensed code. What's more, there are *no dependencies* in the upper right quadrant of the matrix, meaning that *no part of the platform uses or depends on the licensed code.* (Some of the licensed components do depend on the platform, as evidenced by the entries in the lower left quadrant. These dependencies were not considered problematic, because they would not prevent the company from replacing the licensed code with code from another source.)

In effect, given that the two firms had no ongoing relationship, the original crossing point between the platform and licensed code was deemed to be "too thick" for the licensee's comfort. The company thus modularized the software to create a thinner crossing point. By redesigning the software in this way, the firm reduced the platform's specific dependencies on the licensed code; hence its vulnerability to opportunistic "holdup" costs (Williamson, 1985). The modularization can also be viewed as an *ex ante* investment designed to improve the *ex post* negotiating position of the licensee (Grossman and Hart, 1986; Hart and Moore, 1990).

This case vividly demonstrates how transactors may seek to modularize naturally thick crossing points in the task network to reduce transaction costs. Transactional modularization can be a substitute for trust (as it was in this case), hence it is likely to occur when the parties cannot achieve a satisfactory relational contract.

6.2 Modularizations for other reasons

Modularization is a common way to rationalize product and process designs. Engineers modularize in order to (i) manage complexity; (ii) allow parallel work to proceed independently; or (iii) create options to innovate or upgrade subsets of a larger system (Garud and Kumaraswamy, 1993; Ulrich, 1995; Baldwin and Clark, 2000). However, regardless of its intended purpose, a modularization *necessarily* creates new module boundaries, hence new thin crossing points in a task network. Transaction costs will go down at the new module boundaries, and competitors may be able to enter at those points.

IBM's System/360 is an example of such a case. System/360 was the first "truly modular" computer architecture (Ferguson and Morris, 1993). Archival documents reveal that the reasons for modularizing the system were first, to reduce the complexity of IBM's product lines, and second, to make it easier for customers to upgrade hardware without rewriting software (Pugh *et al.*, 1991). The new architecture used design rules to split what had been an integral design into a smaller core and approximately 25 modules (Baldwin and Clark, 2000). This in turn resulted in 25 new thin crossing points at the interfaces of the modules and the core of the system. (This is a case where the core and the interfaces of a system changed as the result of new knowledge.)

Soon after the introduction of System/360, new firms making modules such as disk drives entered the market in competition with IBM. These firms supplied IBM's customers (e.g., large insurance companies) with peripheral devices that had better price–performance than IBM was offering at the time. The transactions between the module makers and IBM's customers were located at the module boundaries created by System/360's new architecture. Such transactions would not have been possible under the older integral architectures because of the large number of dependencies that existed within the core of those systems (Williamson, 1985: 97). But when IBM's engineers modularized the architecture, they replaced those core dependencies with design rules, thereby shrinking the core (Tushman and Murmann, 1998, Murmann and Frenken, 2006). In so doing, they created new thin crossing points with low transaction costs.

IBM's top managers were surprised and annoyed when the new module makers began selling "plug-compatible" devices to their customers (Pugh *et al.*, 1991). The modularization was supposed to simplify the firm's internal operations and improve customer relations, not invite competition. But, in the end, it did all three.

New transaction locations are an unavoidable consequence of modularization, as IBM learned to its dismay. In general, as knowledge about a particular set of technologies grows, the corresponding task networks may be redesigned and modularized for a number of reasons. Such modularizations necessarily create new module boundaries, and vertically integrated firms may split apart or new firms may enter at those points. In this fashion, one industry may devolve into several subindustries coordinated by common design rules (standards) and bridged by intermediate product markets (Baldwin and Clark, 2000; Jacobides, 2005). However, as Chandler (1977) and Fixson and Park (forthcoming) have shown, it is also possible for task networks to become more integral (i.e., less modular) over time. Hence, *there is no process of technological determinism at work driving the task network toward ever-higher levels of modularity*. Instead, the modular structure of the task network at a particular point in time results from the interplay of firms' strategies, their knowledge and the physical constraints of specific technologies. Strategies, knowledge, and technologies all change over time, and as they do, the location of transactions will change as well.

7. Transaction-free zones and the modern economy

In any task network, there are places where the technology of a given time dictates that transfers must be dense and complex. Mundane and opportunistic transaction costs will be high in such locations, and thus transactions between independent parties may not be feasible. In this section, I argue that such areas can—and should—be made into "transaction-free zones" to avoid overburdening the productive system with transaction costs. I define transaction-free zones and explain how they can be *encapsulated* via transactions to create the legal form of a modern corporation. Business units within corporations can also be set up as sub-zones and encapsulated by internal transactions. However, some transaction-free zones, such as those set up by online communities and open source development projects, benefit by remaining *unencapsulated* and open to all comers.

7.1 Transaction-free zones

We have seen that the most economical locations for transactions in a task network are the so-called thin crossing points of the network—places where transfers are easy to define, count and pay for, and information hiding is commensurately high. Transactions can go at thick crossing points as well, but total transaction costs will be higher. Still in many places in the task network, transfers of material and information are *so* dense and complex that the costs of any transaction would be prohibitive.

For example, consider the transfers that occur when a master mold-maker checks on the work of a subordinate. As recounted by Argyres (1996):

> The chief mold-maker, in a routine check of work in progress . . . [saw] that 'friction weld' would set in, causing excessive wear and galling to the mold. . . . A third mold-maker assisted in performing the precision grinding necessary to remove the galling. The mold was saved. (p. 136)

The chief mold-maker's initial check created a transfer of information about the state of the mold. Checking took time, hence was costly. However, the value of this information and the next steps were not predetermined—they depended on the state of the mold. If the mold had been all right, the value of checking would have been low, and the chief would have proceeded to other tasks. But discovery of the mistake triggered a new set of tasks and transfers (of material and information) aimed at saving the mold. In other words, *the task network was not completely fixed, and in response to certain triggering events, it would change on the fly*.

Transient, uncertain cascades of tasks, and transfers like this are extremely common in real systems of production. They occur not only in mold-making establishments, but in disk drive, laptop, plastic, and automobile companies. In real systems of production, simple, stable transfers with low mundane transaction costs are the exception not the rule. Thus, as Williamson recognized, it is impossible to construct transactions that mirror the complex and interdependent transfers in the core of most productive systems (Williamson, 1985: 96–98). Fortunately, humans have devised ways to make transfers without making each and every one a transaction. The basic strategy involves creating a *transaction-free zone*.

Transaction-free zones are physical, virtual, or social spaces where, by convention, a designated set of transfers occurs freely. The smithy and the kitchen were transaction-free zones, as were the disk drive, laptop, plastic, auto, and mold-making companies. Indeed, transaction-free zones are common in human affairs: every time we strike up a conversation, we are in effect creating a temporary transaction-free zone for the transfer of information.

Transaction-free zones are easy to create, but hard to police. Individual property rights, by definition, are suspended in these zones, and, as a result, rational agents may be justifiably reluctant to bring valuable things into them. For example, a public library is a transaction-free zone for books, and most people would think twice before storing their books on its shelves. Similarly, a person with valuable private information would not want to discuss it at a cocktail party where it might be overheard. And the inventor of a device would probably not post its design on a public notice board. Understanding the opportunism of others, we do not usually risk valuable private property or information in transaction-free zones.

However, *transactions can be used to define, count and provide compensation for transfers into and out of a transaction-free zone.* When the library purchases books, they enter the library's transaction-free zone. To check one out, a borrower must sign a card and agree to compensate the library if he or she fails to return the book on time. The checkout procedure is a transaction under my definition: the borrowed book is defined, counted, and (contingently) paid for. Hence the library is a transaction-free zone, but books enter and leave the library via transactions.

Similarly, a person with valuable private information will discuss it under a contract (a transaction) that provides her with compensation and safeguards. And the inventor of a device will contribute its design to an enterprise in return for shares in the company (another transaction). In this fashion, transactions—defined, counted, and compensated transfers—can be used to move things of value into and out of transaction-free zones.

Transaction-free zones in which agents freely access and transfer valuable materials and information are necessary for most forms of efficient production. But a transaction-free zone designed to hold things of value can't have any holes or leaks. Thus, modern market economies have developed sophisticated institutions that provide for the *encapsulation* of transaction-free zones within the boundaries of legally constituted corporations.

7.2 Corporations: transaction-free zones encapsulated by transactions

Defining, counting, and paying for pot hooks is easy. Disk drives, plastics, laptops, and autos are more complex, but, with some effort aimed at transaction design, these transfers can also be made into transactions. However, bringing labor or capital into a transaction-free zone is harder. In medieval times, labor would often enter a zone via birth or bondage: the smith's assistant would be his son or his slave (Bloch, 1961). Capital would enter via marriage, inheritance, or as trade credit attached to a goods transaction (Braudel, 1982). In contrast, today, in modern economies, people are hired and capital raised via transactions.

By definition, it is impossible to precisely define, measure, and pay for all transfers within a transaction-free zone. Hence the transactions that bring labor and capital into the zone cannot perfectly reflect what happens inside. But the legal form of a modern corporation makes it possible to (i) completely surround a transaction-free zone with transactions; (ii) protect the zone from transient disruptions; and (iii) determine whether the zone should survive in the larger system of production. These goals are achieved via a complex social technology (Nelson and Sampat, 2001), which I call *transactional encapsulation.*

Transactional encapsulation involves creating a legal entity—a corporation—with property rights, whose boundaries are defined by its transactions with customers, suppliers, employees, and investors. By design, many transfers within the boundaries of the corporation are complex and difficult to measure and pay for (recall the mold-maker's intervention above). Such transfers are economic only if they take place within a transaction-free zone. Property rights allow valuable things—capital equipment, intellectual property, inventory and receivables—to be held within the zone, without disruption, for as long as the technology demands.

Goods, labor, and capital enter and leave the zone via transactions. Transactions permit the corporation to compensate its suppliers, employees and capital providers, and to receive compensation from its customers. The difference between inflows and outflows of compensation in turn determines the corporation's *financial sufficiency*. If the balance is positive, then, in a market economy, the corporation will have the right to continue as an autonomous, self-governing enterprise. If the balance is negative, the corporation is, by definition, bankrupt, and must be reorganized or liquidated. In this fashion, a corporation can be *an equilibrium in a set of linked games* involving the corporation's customers, suppliers, employees and investors. Hence corporations are institutions in the sense of Aoki (2001).

Over the last 150 years, corporations have become the most common institutional form of business enterprise. Indeed, on this view, corporations can be seen as social artifacts *designed for the purpose* of encapsulating complex transfers. Families, villages, and tribes are also transaction-free zones in which complex transfers take place, but they are not created for this purpose, and they are usually not transactionally encapsulated. Clubs, online communities, and open source development projects are transaction-free zones, which *are* created for the purpose of facilitating complex transfers among their members (Langlois, 2006; von Hippel and von Krogh, 2003). As discussed subsequently, they may or may not be transactionally encapsulated.

Transactional encapsulation via incorporation is a relatively new *social technology*—an institution in the sense of Nelson and Sampat (2001). The technology has changed over time and has also diffused across cultures. Particularly important are the legal concepts of segregating a corporation's assets ("asset partitioning") and protecting shareholders from the corporation's creditors ("limited liability").

These concepts, which evolved in English and American common law over ~400 years (Hansmann *et al.*, 2006), had the effect of completing the ring of transactions around business firms. In premodern times, zones could not be segregated if they were owned by the same person. For example, if a merchant owned two businesses and one failed, the second would be liquidated to pay the debts of the first. Today, if a corporation fails, the other assets of its owners are not affected (limited liability). And if an *owner* fails, the corporations it owns cannot be liquidated if they are financially sufficient in their own right (asset partitioning).

Asset partitioning and limited liability have been adopted as the basic principles of corporation law in essentially all market economies. Thus today a firm that is legally constituted as a corporation can be completely segregated (hence protected) from its owners' affairs. This in turn means that transaction-free zones can be set up to correspond to the modular structure of the task network, rather than being agglomerations of unrelated holdings linked by common ownership.

Finally, there is no need for a central planner to provide coordination *across* encapsulated transaction-free zones, although central planning and control may be useful *inside* such zones. The right of corporations to own property, their ability to engage in transactions at their boundaries plus the rule "only financially sufficient corporations may survive" are sufficient to ensure that a (reasonably) well-designed task network can emerge as a self-organizing, laterally coordinated system without central control.

7.3 Internal transactions and transfer pricing within corporations

Transfers within firms do not have the legal status of transactions between unrelated parties. One division of a corporation cannot call on the courts to adjudicate transfers from another division. Thus corporations are literally transaction-free zones from the perspective of the larger society and the state. Williamson (1991: 274) calls this "the implicit contract law . . . [of] forbearance."

However, organization designers have enormous latitude in designing transfers within corporations (Galbraith, 1977; Tushman and Nadler, 1978). Specifically, they can endow an internal transfer with any or all of the properties of transactions. Thus, inside a corporation, one finds a full gamut of transfer and transaction designs. The most complex and difficult-to-value transfers—for example, problem-solving conversations and consultations—are generally undefined, uncounted and uncompensated. They take place on an as-needed basis. Other transfers inside a firm are defined and counted, but not compensated. And a few will be defined, counted, and compensated according to the corporation's policies.

This last group of transfers satisfies my definition of a transaction. In this sense, Coase, Williamson and the contract theorists are right: some transactions *are* internal to firms. But at the task network level of analysis, internal transactions are a very small subset of *all* the transfers that take place within a firm. Furthermore, I contend, the role of firms and corporations in the economy is precisely to provide transaction-free zones, where complex, but necessary transfers can take place without weighing down the system with the costs of defining, counting and paying for them (Monteverde, 1995).

Interestingly, many transfers within corporations are defined and counted but *not* compensated. For example, in quarterly or annual reviews, most departments in a company go to some lengths to define and count their accomplishments. The legal department will count cases; the IT department will count computations; the product development group will count new products; and the R&D department will count patents and publications. These output measures may be used to justify the expenses of the group, but they measure transfers within the corporation, *not transactions*. Usually, some important dimensions of the group's overall performance cannot be captured in raw output measures, and people within the group are expected to be sensitive to corporate priorities that go beyond the simple measures. Indeed, if a group's contribution to the whole can be captured by a simple set of measures, by definition, *a thin crossing point exists between the group and the rest of the organization*. Such groups are modules in the corporation's task network, and as such are prime candidates for divestiture and outsourcing (Jacobides, 2005).

Finally, many modern corporations have adopted the multi-divisional or "M-form" of organization structure (Chandler, 1962; Williamson, 1985: 279–297). Here, the corporation is divided into individual business units with separate profit and loss (P&L) statements. In these settings, when one business unit provides goods or services to another, organizational designers generally treat the transfer as an internal transaction. This practice, known as *transfer pricing* (Eccles, 1985), is an interesting special case in which a set of internal transfers has all the characteristics of a transaction under my definition. Moreover, divisional boundaries are often modularized to facilitate these internal transactions (Jacobides and Billinger, 2006). Hence, transfer pricing points are—by design—thin crossing points in the corporation's internal structure. As a result, they are potential breakpoints at which the corporation and its industry may split apart into separate corporations and separate industries.

7.4 Online and open source communities: "firms" without boundaries

Corporations are so pervasive in modern market economies that it is easy to fall into the habit of thinking of them as the only economically important type of transaction-free zone. However, with the rise of the Internet, new institutions have developed that are in effect *unencapsulated* transaction-free zones.

In the so-called "commons-based" method of production (Benkler, 2002), interested parties create transaction-free zones in the form of websites and information repositories. Access to these zones is not restricted, but "open." Information flows freely within a zone and can enter or leave it without impediment, hence the zones have very fluid or nonexistent boundaries. Members of a zone collaborate to create some good that all members value, such as a codebase (e.g., Linux), a social network (e.g., Facebook), or an encyclopedia (e.g., Wikipedia). Generally, the good that is created is “nonrival,” meaning that any person can use it without diminishing its use by others.[6] As a result, while there may be free-riders in these zones, there is no tragedy of the commons (Hardin, 1968; Raymond, 1999: 149–150).

Unencapsulated transaction-free zones exist, first, because participants gain more from contributing to them than from remaining isolated. Second, the goods created are nonrival, hence there is limited scope for opportunism. Third, participants freely contribute valuable resources, including information, ideas, and effort, to these zones, and thus there is generally no need to create transactions for the purpose of acquiring such resources.

In these cases, the mundane transaction costs of defining, measuring and valuing what is in the zone or flows out of it become an unnecessary burden on all concerned. Furthermore, vigilant policing of the zone’s boundary (to discourage free-riders, for example) can also deter new members from coming in. Yet, when the good is nonrival, new members’ contributions are a means of enhancing its value for everyone. As a result, even small levels of mundane transaction costs can undercut the productivity of these zones.

Benkler (2002) and von Hippel and von Krogh (2003) have argued that this “commons-based” or “private-collective” model of production is a new organizational form that may come to dominate some parts of the economy. Baldwin and Clark (2006) showed that production in such zones—*without transactions*—can be an equilibrium of linked games, hence an institution in the sense of Aoki (2001).

For purposes of my argument, the existence of unencapsulated transaction-free zones demonstrates that the designers of task networks locate transactions selectively, placing them only where they are needed. Fairly large clusters of tasks and transfers can exist as stable patterns (i.e., institutions) with no transactions within or around them. These clusters of tasks and transfers are arguably “firms” in the sense that they produce valuable goods that compete with other goods in the economy. But although they are visible (as clumps) in the task network, such “firms” do not have transactional boundaries.[7]

8. Conclusion

In this final section, I describe the main contributions of the article, its limitations, and the picture of the economy that emerges from my analysis.

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[6] Information goods are generally nonrival. All designs, thus all innovations, are nonrival.

[7] Recently, some of these zones have been incorporated as nonprofit foundations (O’Mahony, 2003). Members took this step (often reluctantly), in order to assert property rights over valuable products, such as codebases (asset partitioning) and to protect themselves from lawsuits (limited liability). In these instances, two institutional forms were combined to create a third, hybrid form. However, this transition is relatively rare: many unencapsulated transaction-free zones remain in that state for many years.

The article makes four contributions to theories of the firm. First, it views systems of production as networks of tasks. Although not completely new, this view is more microscopic than is typical in transaction cost economics or contract theory. At this more microscopic level of observation, transactions are no longer the basic units of analysis but instead are located in a more complex network structure. The task network itself provides both thin crossing points (module boundaries) and thick crossing points (module interiors). Although transactions can be placed in both types of locations, transaction costs are lower at module boundaries.

The second contribution of this article is to show that many of the opportunistic transaction costs identified in prior work can be traced to the same underlying phenomenon—thick crossing points in the task network. Thick crossing points are places where transfers are complex, numerous, and interdependent. Paths of action and flows of information are consequently uncertain and iterative. We have seen that interdependence gives rise to *asset specificity*. Iterative paths cause some transfers to take place again and again, hence have high *frequency*. And when iterative paths arise in the process of trial-and-error search, transfers are *uncertain*. Thus, thick crossing points are necessarily places with high Williamsonian (1985) transaction costs. In terms of contract theory (e.g., Hart, 1995), when transfers are complex, numerous and interdependent, it is impossible to define, measure, and value each one. Hence any contract written on these transfers will necessarily be *incomplete*. Furthermore, even when participants can observe and judge what actually happened, third parties must rely on indirect evidence. Such transfers are *observable, but not verifiable*. Finally, thick crossing points imply that agents are producing multiple, interdependent outputs, hence they are *multi-tasking* (Holmstrom and Milgrom, 1994).

This article's third (and most important) contribution is a theory that explains and predicts when technological changes in the task network are likely to cause changes in the location of transactions, hence the structure of industries. Indeed, the prediction is very simple: *Modularizations, whatever their stated purpose, create new module boundaries with (relatively) low transaction costs. Modularizations thus make transactions feasible where they were previously impossible or very costly*. Therefore, firms desiring to transact may modularize the task network at the point of their transaction. And firms that modularize their task networks for other reasons should be prepared to face entry and competition at the new module boundaries.

The article's fourth contribution is the concept of transaction-free zones as places in the task network where numerous, complex, interdependent, and iterative transfers can take place economically without the cost burden of transactions. Firms can move valuable items into and out of transaction-free zones via transactions, and corporations can set up zones that are legally encapsulated by transactions. However, unencapsulated transaction-free zones, such as online and open source communities, thrive in the *absense* of transactions. Such communities produce nonrival goods, hence for them opportunistic transaction costs are naturally low, and almost any level of mundane transaction cost may be too high.

Although I argue that transaction-free zones must exist to support many forms of efficient production, this article has little to say about governance or decision-making inside such zones. Indeed, because of the autonomy granted to financially sufficient enterprises in market economies, what happens inside zones is likely to be very heterogeneous. In the first place, organization designers have enormous latitude in the interiors of transaction-free zones. They can use authority, representation, voting, consensus, negotiation, or a complex combination of all of these methods to make decisions and govern behavior. They can set up as-needed transfers, defined-and-counted transfers, and even transactions within a zone, and they can change the pattern of transfers at will (a re-organization). And, in the last analysis, zones do not even need designers. The task structure and norms of a zone can emerge over time, as has happened in many online and open source communities (cf. von Hippel, 2005, Lakhani and McAfee, 2007).

The overall picture that emerges from this analysis is that of an economy-wide task network where densely connected clumps of tasks take place within transaction-free zones. The zones can be (but are not always) encircled by transactions, which provide defined, counted, and compensated transfers between zones. Transactions will tend to be located at the thin crossing points of the network, some of which are created, via modularization, expressly for this purpose. However, transactions at thick crossing points are possible, too, especially when the parties have a longstanding relationship. Speaking metaphorically, this picture is reminiscent of Robertson's view of an economy in which firms are "like lumps of butter coagulating in a pail of buttermilk" (Robertson, quoted by Coase, 1937: 388).

The picture also matches "neoinstitutional" view of Furubotn (2001) of an economy. The task network with its transactions and transaction-free zones is self-organizing and decentralized. At the same time, its elements are subject only to weak selection pressure in the form of local tests of financial sufficiency. Disastrously inefficient firms will fail, *and their transaction-free zones and transactions will disappear with them.* But financially sufficient firms have great latitude in determining their internal structure and external linkages. As long as they remain financially sufficient, they will survive and so will their transactions, contracts, and relationships.

As Furubotn observes, there is no guarantee that a system like this will reach anything approaching global optimality or even constrained Pareto efficiency. But each firm participating in the network will have opportunities to gain advantage by redesigning the portions of the task network it controls and the transactions it influences. At the same time, new firms can quite easily attach themselves to the network at the boundaries of modules. As a result, the network's structure and the location of transactions will be ever-changing.

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