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THE NETWORK AS KNOWLEDGE: GENERATIVE RULES AND THE EMERGENCE OF STRUCTURE

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The imputation problem is how to account for the sources of the value of the firm. I propose that part of the value of the firm derives from its participation in a network that emerges from the operation of generative rules that instruct the decision to cooperate. Whereas the value of firm-level capabilities is coincidental with the firm as the unit of accrual, ownership claims to the value of coordination in a network pit firms potentially in opposition with one another. We analyze the work on network structure to suggest two types of mechanisms by which rents are distributed. This approach is applied to an analysis of the Toyota Production System to show how a network emerged, the rents were divided to support network capabilities, and capabilities were transferred to the United States.

The thesis of this article is that a structure of a network is an emergent outcome generated by rules that guide the cooperative decisions of firms in specific competitive markets. The observed differences in the patterns of cooperation across industries are not happenstance. They reflect rather the implicit operation of these cooperative rules and the competing visions that come to shape a network. The emergence of the structural pattern of cooperation is not the result of an abstract and static choice between market or firm, or market versus hybrid cooperative forms of governance. Structure is emergent in the initial conditions of a specific industry.

The structure of an industry is interesting, because it represents capabilities of coordination among firms, as well as claims on the property rights to profits to cooperation. The conventional emphasis on the opposition of market, contract and firm represents largely a static view of the boundary choice facing a firm. The common proposition that a viable firm is worth at least the sum of its parts rests on the supposition that

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for knowledge even when shared among two firms may not be a public good in the conventional sense of this term, that is, information that is accessible to other parties at zero marginal cost. For coordination among firms itself entails principles of organization that can be idiosyncratic to their relationship and that code for particular kinds of capabilities, such as speed of product development or minimizing inventories.

The accounting for knowledge stumbles, consequently, on an important problem: how do we impute the knowledge external to the firm that nevertheless contributes to its profitability? This puzzle is related to the interpretation of "total factor productivity" in macroeconomic growth accounting studies. After accounting for the contribution of inputs to economy-wide growth, the residual is attributed to exogenous technical change, institutional factors, or externalities. Alternatively, it is possible to specify explicitly the 'imputed' source of productivity gains:

$$y_i = a_t + \gamma a_m + \sum_i a_i X_i + R$$

where y_i is output of firm i, a_t is a shift parameter, $\alpha_i X_i$ are weighted inputs (such as the value of capital and labor), R is a residual, and γa_m is the weighted value imputed to the fixed effect of membership in a network (all terms are in logs). This formulation proposes that "network capability" is a source of imputed value to the productivity of a firm.

The most tangible expression of the direct value of external knowledge to the firm is the compelling evidence that rapid product development depends on the reliance on outside suppliers. Both Clark, Chew and Fujimoto (1987) and Mansfield (1988) found that time to market was speeded through a policy of outsourcing to suppliers. The capability to commercialize products can in this case be seen to rest on the successful exploitation of the knowledge of other firms. In this sense, the competitive capabilities of a firm rest not only on its own knowledge or on its knowledge of the network. The capabilities of the firm, rather, are dependent upon the principles by which cooperation among firms is coordinated and supported in the network.[1]

This view of the network as knowledge confronts four analytical challenges:

1. What is meant by network capabilities?
2. How do we understand the generative rules that drive the emergent structure of the network?
3. How does structure influence the competing claims to rents among members to a network?
4. If structure encodes emergent knowledge, how is the network transformed into intentional replication of this knowledge through time?

The contribution of this paper is to understand networks as arising out of generative rules that guide the formation of relationships and code for organizing principles of coordination. These rules are "sorting" provisions that indicate the match between firms and the nature of their cooperation. The rules code for principles (e.g., "share research" or "supply just on time") and in turn lead to network capabilities that are not specific to a firm, but represent joint gains to coordination and learning. We explain that the structural patterns that emerge in a network define two kinds of rents, one that accrues to a broker, the other more broadly to the members of a closed group. Because these capabilities are quasi-public goods to members and yet firms are the units of accrual—not the network, a central issue is how the rents to this coordination are made both exclusionary and sustainable in the face of potential defection.

Our reasoning rests upon three central ideas of what define a firm: unit of accrual, governance structure to resolve agency problems through residual claims, and a repository of coordinating capabilities and social identity. While these three ideas are operative in the analysis below, we stress, in particular, the latter property of the firm in order to analyze how capabilities are generated by network coordination. To shift the understanding of networks as simply a resolution to agency conflicts, or as access to information, to their capabilities in promoting variety and yet coordination in specific industry settings is a primary ambition of this paper.

[1]Most, if not all studies of networks treat knowledge as the question of knowing who has knowledge and the access of this knowledge through cooperative relationships. (See Powell, 1990, for example.)

Specialization and variety in market and networks

A definition of an economic network is the pattern of relationships among firms and institutions. In this definition, an idealized market is a polar case of a network in which firms transact at spot prices and are fully connected in potential transactional relations but are disconnected through their absence of cooperative agreements. Few markets exist of this type. Rather, most markets consist of sub-sets of firms and institutions (e.g., universities) that interact more intensely with each on a long-term basis. These patterns of interactions encode the structural relationships that represent the network.

This definition fails to convey the observation that the structure of a network implies principles of coordination that not only enhance the individual capabilities of member firms, but themselves lead to capabilities that are not isolated to any one firm. It is important to the following argument to distinguish between information and coordination (or what is also called know-how). At a minimum, the ability of a firm to access information in a network constitutes an advantage, e.g., the effect of accessing the technology of a research center on its subsequent innovations. Of course, this access is most likely the outcome of a bargain, in which the two parties arrive at an understanding of contribution and compensation. This sort of access, stressed by Powell (1990) among others, exemplifies the informational benefits of enhancing a firm's capabilties through relationships.[2]

Cooperation, however, can also engender capabilities in the relationship itself, such that the parties develop principles of coordination that improve their joint performance.[3] Such principles might be rules by how supplies are delivered, such as by just in time or mass production. Or they might involve more complex rules governing the process by which innovations are collectively produced and shared. In this sense, the network is itself knowledge, not in the sense of providing access to distributed information and capabilities, but in representing a form of coordination guided by enduring principles of organization.

The proposition that part of the value of a firm can be imputed to the capability of its embedded network is implicit in the treatment of the division of labor as handled by Smith through Stigler. The now classic question in the analysis of the boundaries between markets and firms can be rephrased as the following: if networks are structured by organizing principles of coordination through a division of labor among firms, then why are these firms not organized within a single common governance structure?

Networks offer the benefit of both specialization and variety generation. The superior abilities of markets to generate variety is a commonplace belief that is, nevertheless, problematic. The converse of this statement is that firms are superior vehicles for the accumulation of specialized learning. To understand variety, we must also understand why specialization and variety are antithetical within the firm, but define complements within a network.

Smith's famous essay recognized the power of the market to achieve variety through specialization in the division of labor (Smith, 1965 edition). Smithian efficiencies in specialization were due to the inherent learning by doing by completing repetitive tasks, as well as the reduction in loss time due to changing tools and tasks. At the heart of Smithian efficiencies is the implication that learning by doing, despite the initial endowments of equal competence among individuals, accumulates to lower the costs of subsequent production. Smith saw the division of labor as derived from the dynamic learning through specialization. He posited that people were largely similar in their a priori talents; differentiation into specialized competence was the outcome, not the precursor, to the division of labor. In other words, specialization through a division of labor is the driver of the acquisition of competence and, consequently, of knowledge.

The perspective of the firm as a repository of knowledge embraces Smith's observation on experience-derived learning through a division of labor as posing both a static coordination problem

[2]See Gulati (1998) for a discussion of information and network formation and Palmer, Jennings and Zhou, 1993, for cohesion studies on innovative diffusions. Early studies on the idea of competition among alliance networks are Nohria and Garcia-Pont, 1991, and Gomes-Casseres, 1994. The intriguing idea of "communities of practice" is also akin to this perspective, in which "connectivity"—rather than position in a network—is a source of advantage. See Brown and Duguid (1991).

[3]Studies on the capabilities of networks are explored in many studies on Italian and German networks, e.g., Lorenzoni and Baden Fuller (1995), Lipparini and Lomi (1996), Herrigel (1993) and Piore and Sabel (1994).

as well as determining dynamic paths of knowledge acquisition. Firms are social communities that permit the specialization in the creation and replication of partly tacit, partly explicit organizing principles of work.

But why are firms required to provide this coordination? The behavioral sciences provide an important insight. (See Kogut and Zander, 1996, for a review.) Boundaries to a firm represent more than the legal unit of accrual; they provide the cognitive representation of what constitutes the object of membership, that is, of identity. Through identity, individuals anchor their perceptions of self and other and attach meaning to membership in a firm, as well as in the categories of skill that define a division of labor (e.g., "worker" or "accountant"). By this anchoring, they employ focal rules by which action is coordinated and intention communicated through common categorization of self and other. More importantly, through identification to occupation and firm, individuals are guided and motivated along coordinated paths of joint learning. Boundaries matter, because within the cusp of these social membranes, identities are circumscribed. The behavioral foundations to why the knowledge of the firm is bounded are to be found in the basic human motivation of belonging and membership.

If benefits of identity are to lower the costs of communication and coordination, they come at a cost. For identities represent a norm which indicates avenues of exploration; by implication, they also prohibit certain paths. Organization by firm is variety reducing. The great power of the market is not only its information properties, but also its function as a generator of variety in innovations and capabilities that are subject to selection. The "market", as an assemblage of firms pursuing different visions and organized by distinct identities, generates a variety that individual firms cannot manufacture internally without decrement to division of labor and the salience of focal rules, i.e., to the organizing principles (inclusive of compensation and incentive schemes), by which work is coordinated.

In effect, a rent arises out of the scarcity value not only of land or technology, but also of behavioral coordination within the firm. Yet, at the same time, networks also provide capabilities to coordinate behavior among firms. This dynamic between the capability of the firm and market lies at the heart of Stigler's argument that a firm moves from vertical integration to disintegration of its activities according to the process by which a market "learns" to supply inputs at a lower cost than it can itself (Stigler, 1951).

These observations are important because they force a recasting of the received wisdom on the relative merits of markets—which we have indicated is a network—and firms. Curiously, the initial statement of Coase is compatible with the view that the structure of external relationships influences boundary between firm and market. Coase (1937) posited that this boundary is determined by the internal costs of production and management relative to the costs of market search and procurement.

Coase, however, left unexamined the issue how structure reduces the costs of search and coordination. Just as Stigler pointed to learning in the market, Chandler's (1962) early contribution was to explore how higher-order organizing principles of divisionalization could reduce the costs of internal complexity. His history of the innovation in internal hierarchy pointed to the role that structure plays in reducing the costs of coordination and authority. More importantly, divisionalization increased the internal variety of the firm by separating potentially competing visions into relatively contained units.

Figure 1 presents a diagram of the Coasian firm as the base case. Since Coase acknowledged market search and management costs, it is reasonable to think of these costs as increasing as the variety of products are produced internally or sourced externally. We index these costs as increasing in relation to a set of products that reflect the identity of the firm. At low variety, a firm produces at lower cost than purchasing from other firms; this condition is simply to guarantee the existence of the firm. At some point, the internal management of increasing variety becomes more expensive than sourcing variety from the external network known as the market.

It is then straightforward to diagram the effect of a Chandlerian innovation; it increases internal variety at given levels of cost. Similarly, we can think of Stigler's life cycle notion of integration and de-integration as implying an improvement in the capability of the network. Just as a firm learns, so does the network insofar that suppliers come to substitute for internal production. In effect, the variety of the firm decreases as the knowledge diffuses to the market. Figure 1

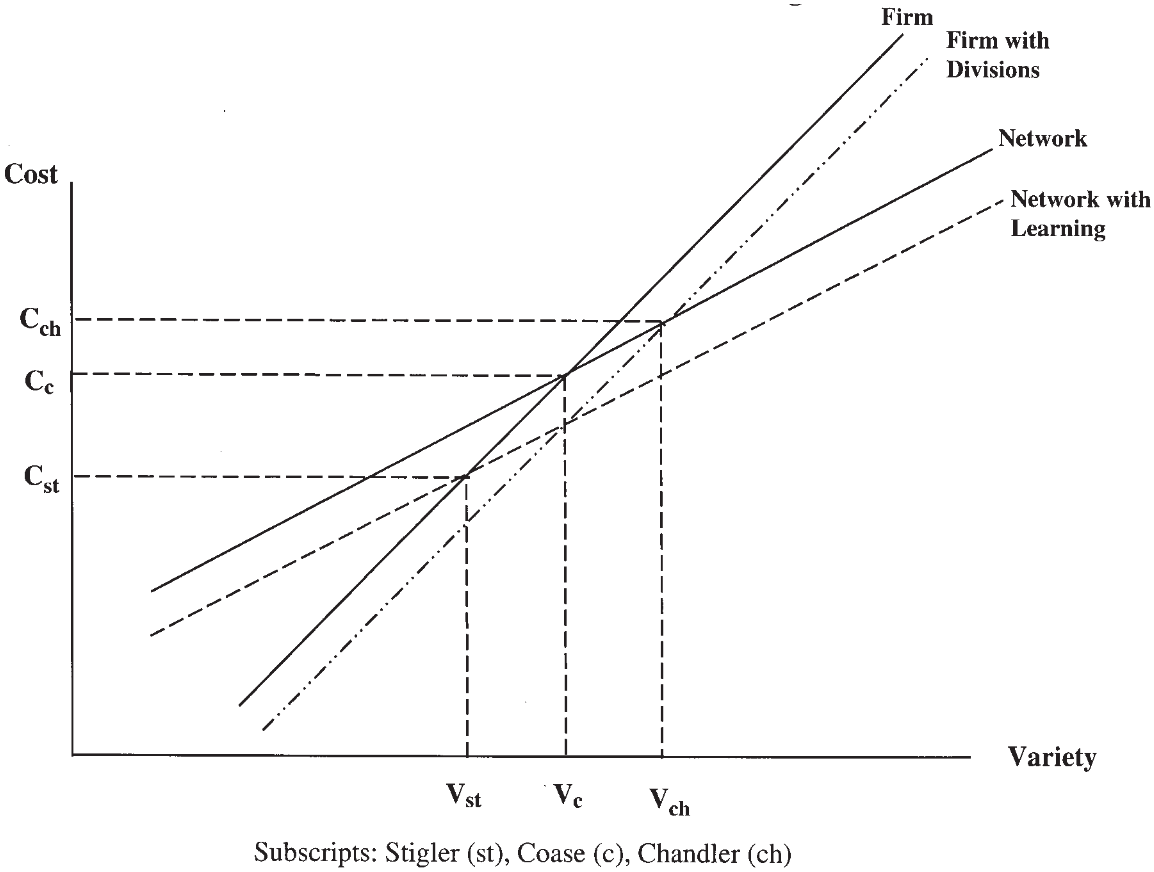

Figure 1. Static costs of sourcing variety with organizational and institutional learning

illustrates this idea by showing how improvement in the efficiency of the market reduces the internal variety of the firm. As the market learns, the need to integrate vertically dampens. It is, in fact, exactly the increased knowledge in the supplier network, as realized through the innovations in the Toyota system, that has forced a radical disintegration of American auto assemblers. Gulati and Lawrence's (1999) observations on the extension of coordination to the external value chain are drawn from the historical diffusion of these innovations in the auto industry.

Simple rules and emergent networks

A network is then a collection of firms, each ensconced in an identity that supports specialization and a dynamic of learning and exploration. But the network, unlike the firm, does not consist of an authority relationship that can enforce an organizational structure on its members. In Chandler's history, an entrepreneur imposes an innovation on the firm with the support of top management. How does a network learn to coordinate in the absence of authority?

The seeds of the answer to this question lie in Hayek's contention that the market is the engine of variety (Hayek, 1988). Hayek's contribution is often credited for his observation that markets are superior to hierarchies for embedding information in prices. But Hayek, even in his heralded 1945 article on information, meant something more. Knowledge is held tacitly, raising the problem of how central planners could ever know as much as decentralized firms. Specialization is self-preserving, even if markets generate information as to their valuation and accessibility, because prices can be communicated, but not competencies. The dynamic advantage of the market is the generation of variety through an "extended order" that supports coordination among specialized firms.

Hayek's notion of the extended order begs the question what generates the structure of this order, or what we would label the network. Obviously, markets differ from each other. The extended order supporting variety is hardly homogeneous across industries. Is the emergence of these network structures random or do they reflect the operation of operating principles that act as genetic rules?

Our claim is that the structure of a network arises from inherent characteristics of technologies that populate an industry, as well as social norms and institutional factors that favor the operation of particular rules. Technologies of mass production, which characterize some industries in some countries, influence the choices that firms make to cooperate or not. Industries characterized by science-based technologies tend toward rules that promote cooperation between research centers and firms. As these rules generate the structure of a network, the structure itself influences subsequent behavior.

For clarity, consider the simple example of the tit-for-tat rule as analyzed by Axelrod and Hamilton (1981). By analyzing the convergence properties in a population in which agents use different rules for cooperating and defecting, they found that particular rules, especially one that rewards for cooperation and sanctions for defections on the next round, tend to dominate. Convergence, however, is frequency dependent and thus vulnerable to tipping in either direction. The implication of this analysis is that structure that isolates "cooperators" tends toward self-organizing communities of cooperation.[4] There is no authority, and yet the network self-organizes—that is, converges—toward the dominance of rule (e.g., tit-for-tat) over the other. Once achieved, the resultant structure supports a general capability of cooperation without even enacting the rule itself.

There are many studies whose results imply the operation of rules generating a dynamic of self-organization. These rules need not be technological in origin, but can also reflect institutional and cultural norms. They are also deeply embedded in the social identity of the actors. They may seem "irrational" from a perspective of economic optimization. But what is critical to understand, as we will explain later, is that rules generate structure that dissuades rule-breaking behavior.

That identities underline the preference for particular rules is central to White's argument that networks are manifestations of the physics of identity and control (White, 1992). This claim is implicit in White's early work on the structural implications of kinship rules (White, 1963). (This analogy is not far-fetched in light of the penchant for using familial descriptions in the alliance literature, such as "parent" company or joint venture as a "child".) Societies differ in their rules by which kinship encourages and prohibits marriage. As a consequence, kinship rules generate distinctive trees. Rules that permit marriage between first cousins generate radically different societal patterns of kinship than those that forbid marriage only between paternal cousins. The identity of what constitutes family is the foundation to the origins of the rules that govern familial replication.

In traditional societies, identity and family determined the economic and social networks. The study by Padgett and Ansell (1993) infers the rule, based on the analysis of the marriage and economic networks of Florentine families in the fifteenth century, that aristocratic families did not interact socially or economically with the new families. These families were situated in a fairly simple economic and social network determined by economic and marital rules. By mild violations of the rule forbidding economic ties, the Medici family influenced the structure such that they were two times more central in the network than the next family (Wasserman and Faust, 1994).

The rules of kinship and social prestige have clear analogues in the implication of identity within the social community of industrial and financial firms. For example, the results observed in the study by Podolny and Stuart (1995) on cooperation are based on the rule that high status firms do not ally with low status firms. As a consequence, there is a sorting behavior by which prestigious firms are grouped by strong ties (cohesive ties with no intermediaries) and engage in weaker ties to less prestigious firms, sometimes as a form of endorsement (Stuart, Hoang, and Hybels, 1999).

Despite our emphasis on the neglected social

[4]For an insightful analysis of how structure influences diffusion (e.g., cooperation) by agents, see Boorman 1974. The parallel between the proposal to understand structure as emergent and rule-based shares obvious affinities to the literature on complex adaptive systems; see Axelrod and Cohen (2000) for a treatment. The genetic algorithms in the vein of Holland (1992) are an appropriate research strategy by which to think about rules appropriate for stylized industry conditions. Empirically the identification of rules may be fairly simple, as I try to illustrate in the subsequent examples in this article.

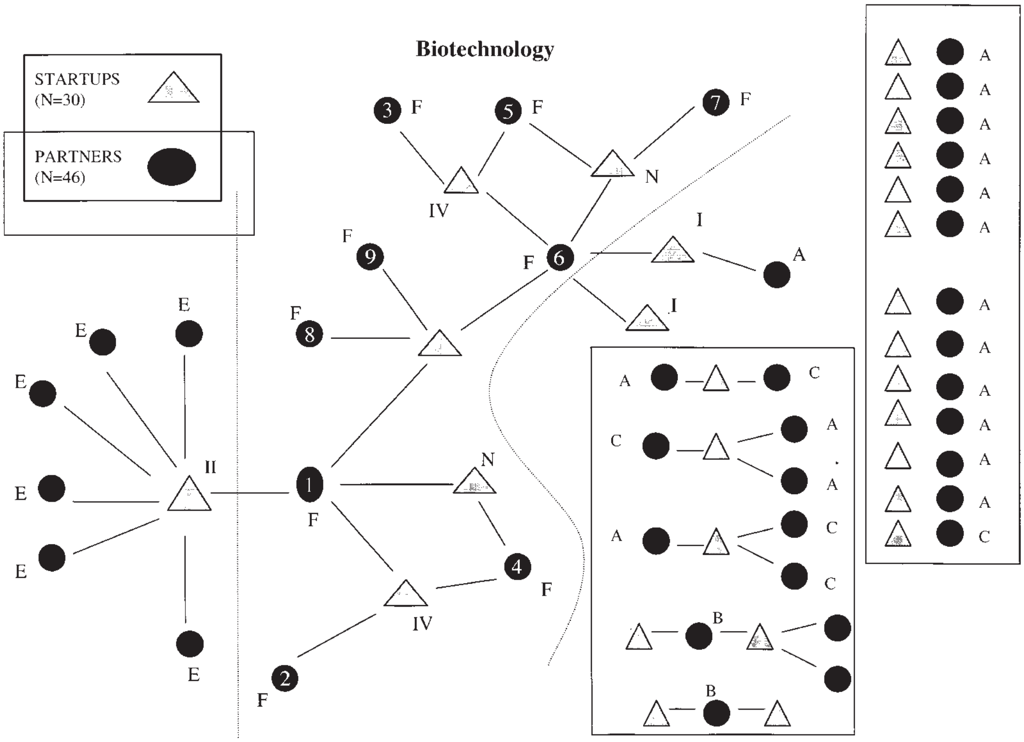

Figure 2. Biotechnology

influences on cooperative rules, technological factors are obviously critical to understanding networks in modern economies. The study by Axelrod et al. (1995) on standard setting for the Unix operating system assumes that because of technological complementarities, firms are encouraged to cooperate. Competitive pressures suggest a mating rule in which firms prefer to ally with distant rivals.[5] In this case, a sorting rule is derived from competitive rivalry: avoid cooperation with near rivals. From this simple rule, they show that individual cooperative decisions among "agents" (i.e., firms) generate a distinctive structure over time, with two groups formed around competing standards. The results of their simulations, using empirical data for variable values, underscore how identities correspond strategically to competing visions of the future (e.g., distributed versus central computation, cable versus satellite transmission).

The tendency of some industries to converge toward what Gomes-Casseres (1994) calls competing constellations varies widely across industries. The emergence of structure in a network is sensitive to specific industry settings. Competing around standards is not, for example, a feature in the pharmaceutical industry. The rule in the American biotechnology industry was the following: start-up firms should form alliances with established companies. The origin of the rules lies principally in the lack of financial resources and marketing and distribution capabilities of the start-up companies. Venture capitalists, concerned by the "burn rate" of the initial capital provisions to these companies, required relationships to avoid costly expenditures and to signal the quality of the drug portfolio.

The outcome of these rules is a pattern of alliances that as early as 1983, as shown in Figure 2, are marked by the creation of several fragmented star and hub sub-graphs that reveal an emergent structure. (The structure is generated on the basis of the block-model data in Table 3 of Walker, Kogut and Shan, 1997.[6]) Sometimes

[5]Note the study of Baum, Calabrese and Silverman (2000) has the contrary assumption that distance provides the benefits of new information, a weak tie argument. As we note throughout this paper, both assumptions (or rules) can be right, depending upon the industry context (e.g., standard setting versus competence seeking).

[6]I thank Jon Brookfield for suggesting this graph.

established companies are relatively central; in a few instances, a new biotechnology company emerges as central. Overall, the network structure is very sparse, and yet there is an identifiable structure.

The rules in the biotechnology industry that generate the relational structure are themselves products of the non-random distribution of capabilities that distinguish start-ups and pharmaceutical companies. Start-ups, consisting of molecular biologists, lacked certain capabilities. But by implication, pharmaceutical companies were unable to integrate the new science, built upon particular professional identities, with their traditional research endeavors. Identification limited, at least initially, the internal variety of pharmaceutical companies (see Zucker and Darby, 1995). Specialized by differentiated capabilities, their mutual need suggested a rule of relationship formation that generated distinctive patterns in the structuration of a cooperative network.

For this reason, the emergence of structure in biotechnology industries outside the United States followed a different trajectory. Here we see the importance of understanding the conjunction of technological and social influences. Because scientists in France identify professionally with national scientific laboratories, small firms were impaired in attracting the critical scientific talent (Gittelman, 1999). In this network, laboratories have remained critical nodes in the network, with dense ties formed with national laboratories. Thus, different ideas of professional prestige in conjunction with the technological properties of genetic engineering research resulted in a dramatically different network structure in France, one built around laboratories and large firms.

This dynamic between internal capabilities, ensconced in specific identities and organizational structures, and the external knowledge in the market drives a co-evolution between the emergent properties in the firm and network. Even though markets and firms are organized by different principles, there is nevertheless a correspondence in their structure and properties. We return here to Smith's and Stigler's arguments that differentiation in the knowledge of the firm and market influence boundary decisions.

The findings of Gittelman suggest the grounded speculation that the dialectic between specific markets and individual firm competence drives a co-evolution that enjoys a reflection in the structure of the network. An example serves to illustrate this correspondence. The excellent study by Annalee Saxenian (1994) compares the structure of semiconductor and computer industry networks in the Silicon Valley and Route 128. She found that the two regions had very different network structures, even though the technologies and industries were the same. In Figure 3, we graph her ethnography. The top panel shows a hierarchical structure in Route 128; a few large firms dominate smaller companies. The Silicon Valley shows a decentralized network. Is it a coincidence that the internal structure of the Silicon Valley is described as flat and that of the Route 128 firm as hierarchical? Why should the internal structure correspond to the external structure?

In the case of the Silicon Valley, there is an institutional foundation that supports the flow of information and matches engineer to project and firm. Obviously, it is rarely in the interest of the current employer to see proven research talents exit their firm, and it is in their interest to discourage involuntary exits. The evolution of a labor market for talent counters potential negative sanctions by the current employer. That is, there are a sufficient number of job opportunities so that in the event the engineer exits in the future (because the hiring firm dies or the new project opportunity ends), subsequent sanctions by former employers are unlikely to be effective. A market consisting of many small networked firms cannot generate effective sanctions on the mobility of engineers. There is, as a consequence of high

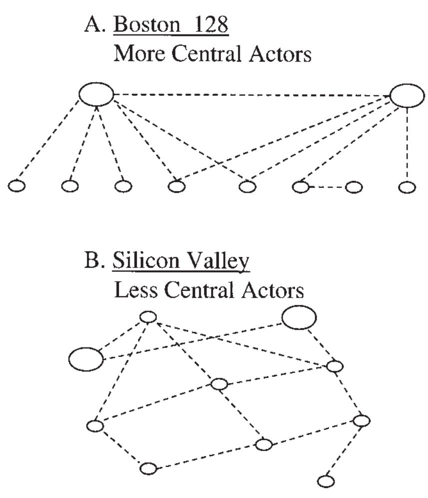

Figure 3. Saxenian's ethnographic description

mobility, less motivation to build a vertical hierarchy by which to promise future rewards.

A labor market that is dominated by a few large firms permits sanctions through refusal of these firms to rehire the engineer or through their signals to other client firms in the area. These sanctions need be no more than the loss of relative ranking in the internal hierarchies of these dominant firms. (Note that the internal labor markets of Silicon Valley are characterized as flat; tall hierarchical ranks are not viable if labor market mobility is high and work is organized by projects.)[7] If a regional market does not support labor mobility, then individual engineers are likely to seek internal advancement, or—and it is important to stress this implication—to migrate from the region. (See Almeida and Kogut, 1999, for evidence.)

The theoretical link between internal and external structure begins from the recognition that firms and markets are jointly emergent phenomena embedded in spatially-defined labor networks. Their structure reflects the emergent properties that influence information and incentives, as well as the know-how and coordination, that inform firm and individual strategies. The structural opportunities through labor market has a powerful effect on differentiating the orientation of professional identities. In the hierarchical network of Route 128, engineers identify themselves with internal labor markets; the Silicon Valley encourages identification along professional competence in projects.

The comparison between the Silicon Valley and Route 128 raises the important distinction between emergence and intentionality in network structure. Networks are rarely formed by design, but rather they emerge initially in response to the institutional and technological opportunities of an industry or field. During this process of formation, relationships develop out *informational* properties that drive a matching process among firms. However, over time, knowledge that is initially information gradually becomes encoded in persisting structures that influence subsequent behavior in two distinct ways: as a conduit of information and as the basis of *coordinated action*.

Structure in a network is thus not determined just by exogenous factors, but is an expression of competing and evolving rules that guide the behaviors of interacting entities. Sometimes, inherent technological characteristics favor the emergence of particular rules. A technology that enjoys scale economies tends to generate large firms; another technology, such as microprocessors (see below), tends toward network externalities. These characteristics influence size distributions and the structure of a network. Similarly, institutional contexts (e.g., socialist or capitalist, German or American legal environments, etc.) influence the origins and formation of networks. Institutions, such as governments, sometimes dictate rules. A rule that establishes monopolies compared to another that regulates prices has dramatic implications for the emergence of industry structure and organizing principles of coordination and competition. The effects of government discretion generated widely different industrial and relational structures among countries (Hughes, 1983). Because markets and firms are not simply given constructs, but arise from varied institutional origins and technological influences, there are no generic rules that are exogenous and known a priori. Rather, the systemic interaction of technological, social, and institutional factors influence the evolution of network structure.

Capabilities and rents

In an economic network, a firm is legally constituted as the unit of accrual. Hence, cooperation and coordination in a network pose the questions whether there are rents in networks and to whom do they accrue. An answer to these questions requires an understanding of the location advantages to only information access in a network compared to membership in a coordinated network. In other words, we are interested in understanding the conditions by which certain network structures generate value that is captured differentially by participating firms through their coordination.

Call the first type of advantage a Burt rent. Burt describes the generation of network structure as the outcome of the competitive struggle among egos motivated by envy and self-interest. The key

[7]This line of argumentation comes closest to Coleman (1990: 439ff.), who assumes that external labor markets are competitive markets. He thus does not consider the relationship between the type of external and internal labor markets and its effects on the location of innovation. For an analysis of a related problem, see Anton and Yao (1994).

construct for Burt is the notion of "non-redundant" ties. A tie is non-redundant if it represents the only path between two nodes as constituted by individuals, firms, or even industries. Entities that have multiple unique (i.e., non-redundant) ties with other nodes who are not connected occupy powerful brokerage positions called "structural holes." Burt has argued that firms that are positioned in structural holes are more powerful because they arbitrate the infor-
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organizational payments to members in an amount that violates rules of proportionality.[8] Whereas Burt implies that this group rent flows to the broker, a Coleman network claims that the gains to superior coordination must be distributed in ways to assure participation. Thus, different notions of viability are a critical distinction between Coleman and Burt networks.

The importance of understanding viability is implicit in the examples discussed earlier. For example, the study by Axelrod et al. (1995) relied upon Nash equilibrium. A coalition is only viable to the extent there is no improvement for any firm to defect to the other coalition. For a Saxenian network to function, individuals in a hierarchy must view this as more rewarding than defecting to a start-up. A hierarchical firm is not viable in Silicon Valley, because individuals will choose to switch jobs in that institutional setting.

The study by Walker, Kogut, and Shan (1997) explored both Burt and Coleman types of networks. The early history of this industry revealed a network that was relatively unstructured and more like a market. Certainly, while entrepreneurs had important affiliations to sources of ideas (e.g., universities) or finance, horizontal ties among firms were weak.[9] In this type of network, market-like relationships emerge through firms communicating information regarding e.g., prices and specifications. Coordination in this instance happens through transactions governed by price signals. Learning takes place through the revelation of cooperative or dishonest reputations.

Over time, a more complex network emerges. Figure 2, shown earlier, represents a relational structure that reveals both structural holes and Coleman-type networks. The pharmaceutical company marked II is an isolate that has non-redundant ties with 6 start-up firms; it clearly occupies a structural hole. However, some firms, such as those in group IV, engaged in more dense transactions that are suggestive of formative type of Coleman networks. The analysis of subsequent relationships revealed that Coleman network based on coordination, inclusive of mutual know-how exchange, emerged. Because of this social capital, firms belonging to the same groups tended to cooperate with each other subsequent to their initial cooperation. Network structure began to replicate itself in stable patterns of enduring cooperation. It is not simply that biotechnology relationships are enduring across years that explains this persistence. It is rather that these formative groups formed progressively more closed cliques; the flow of new relationships was influenced by Coleman-type incentives for cooperating firms to deepen their cooperation. This pattern is also implied in the findings of Gulati (1995) who shows that partners tend to ally with those close to them in the network and with whom they have previously allied.

The emergent properties of networks ride on self-organizing processes that tend to freeze the structure among firms over time into stable patterns of interactions. The Walker et al. (1997) study noted that a danger to a Coleman network is that it limits search and can reduce variety. Uzzi proposes that the optimal network structure in the textile industry has a high density of relationships among firms, yet while allowing new entrants and the possibility of further exploration. Since the advantage of the market is the generation of variety, too much structure reduces innovation. Of course, to the extent firms who defect from cooperation are eliminated, this reduction is desirable. On the other hand, the constraints on individual experimentation increase due to requirements to orchestrate coordination with other actors. The more networks take on the properties of firm organization, coordination deprives individual firms of potential avenues of exploration. Thus, neither Burt, nor Coleman structures can be ranked a priori for their welfare merits; additional structure to the analysis is first required.[10]

It may help to analyze this line of debate by

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[8]This description is similar to the theory of clubs (and to Olson-type of selective incentives among small groups). There are many rules by which individuals can be rewarded that satisfy their reservation price (i.e., minimum for staying a member). See Cornes and Sandler (1996) for a summary.

[9]See Powell, Koput and Smith-Doerr (1996) on ties.

[10]See the discussion in Walker et al. (1997) on the potential for dense relationships to drown out experimentation and learning. Rowley, Behrens, and Krackhardt (2000) provide an excellent review of the relationship of strong and weak ties to exploration, with evidence indicating the importance of industry context in evaluating the relationship of structure to individual firm performance. See also the discussion by Walker (1998) on the search models indicating that weak ties proliferate from the objective of maximizing information access. This notion of the proliferation of weak ties is similar to Khanna, Gulati, and Nohria's (1994) notion of alliance scope. See also Baum et al. (2000), and the comparison by Zaheer and Zaheer (1997) of structural holes and weak tie arguments.

anchoring the discussion in a few empirical facts. The primary observation is that alliance networks are exceedingly sparse. If there are 100 firms in a network and if we only count ties as nondirectional (we ignore who sends and who receives), then we expect there to be 4950 potential ties. (We code a tie as 0 or 1, regardless of how many agreements two firms may have with each other). If we think about these ties as forming different coalitions of players, then we have a 2 to the n problem defining the solution space for potential membership in 2 coalitions—2 because a firm can choose to join or not join.). For a 100 firm network, there are then 2^{100} possible combinations in membership. Despite the combinatorial richness in potential alliances, empirically, we see networks that are sparse (i.e., the actual ties are far below the maximum) and that engage in rather limited experimentation over time regarding the changing identity of coalition partners.[11]

It would seem that sparse networks favor a Burt-like description of many structural holes. But another way to think about the strategic implications of stability in what appears to be self-organizing patterns of cooperation is to ask how sensitive are these groupings to defection of partners. (In the theory of graphs, this exercise is akin to asking how robust is structure when x of k edges are reassigned randomly among n vertices.) After all, where there are rents, there are bound to be strategies to alter the structure by new alliances. An important test for the likelihood of success of a strategy is to compare Coleman-type structures (i.e., dense ties among few actors) and Burt-type structures (broker firms with few redundant ties among its satellites) for robustness.

The recognition that the results of this comparison are easy to predict reflects the stability of structure *despite* very sparse networks. Social networks are fairly stable to random perturbations (at moderate probability) because structures tend to be localized.[12] This statistical result is strengthened if we admit ties are not randomly assigned, but tend to follow generative rules that encourage cooperation among firms already cooperating. After all, the advantage of membership in a local club promotes further cooperation among members. There is, in other words, considerable order despite rather low density of cooperation and the potential for a multitude of alliance structures. It is not surprising, then, that industries (or any community) vary in their structures, and yet share the property of tending toward self-replicating patterns of cooperation.

Yet, despite the tendency of a Coleman network to generate incentives for replication even in sparse networks, we are unlikely to arrive at a robust finding regarding global or group welfare. In one industry, the advantages of standard setting suggest that one rule for determining the decision to cooperate is to join a big coalition (Axelrod et al., 1995). Following this rule, for example, in Uzzi's textile industry butts up against a more appropriate rule to sort by prestige among low and high quality designers. It is not surprising that empirical results seem contradictory, when they reflect differences in the properties of given networks.

Similarly, caution is required to assume that Burt networks are not stable and converge over time to a market network. (Burt, 1999, views structural holes as dynamically unstable.) It is important to avoid the logical fallacy of attributing persistence to genesis. Once structures are created, we need to ask what sustains them. Because action is constrained in emergent networks, the late recognition of how defection can benefit an individual firm may be inconsequential; that is, the firm cannot act upon it. Partners may not be available and may be unwilling to defect; switching may be costly and promise only uncertain advantages. Again, the notion of viability is critical. Defection may be prohibited because of sanctions imposed by the group. Or, for Padgett's and Ansell's medieval Florence or for Poldony's and Stuart's semiconductor firms, defection is deterred because the identities of membership in a group dissuade alliances with less prestigious families or firms. For either motive—economic or social sanctioning, the preferred strategy may be one of local replication, such as imitating the supplier strategy of a competitor, than creating short-cuts in the hope of destabilizing a fairly immobile structure. In theory, there is no clear reason to believe that structural holes are not sustainable.

[11]See Kogut and Walker, 1999, for a discussion of some examples.

[12]For simulations of the robustness of local structure (that is, small worlds) in sparse networks, see Watts and Strogatz (1998).

Property rights and network centrality

Of course, another way in which the emergence of structure is not only influenced, but also sustained, is through property rights. A basic property right is the ownership by an individual of the use of natural endowments, such as skill. Of course, if human capital were alienable from the person, it too would flow like a resource through a network, diminishing its value. It is, however, the stickiness of human capital that influences a person's eligibility to play a brokering role. The tacitness of firm knowledge similarly makes a firm less susceptible to the competitive imitation of its claim to broker.

This confounding of position in a network and attributes that makes one firm more central than another poses an econometric problem of selection bias. Rents may accrue to "quality" people or firms who therefore occupy structural holes.

In this regard, ownership of an innovation that is property right protected is an attribute that influences the generation and appropriation of rents independent of network effects. Yet, even here, the causality behind the generation of rents is complex, and the structure of the network becomes an endogenous feature in competition among innovators. It is important to emphasize that cooperative agreements are frequently concessions that permit the utilization of one firm's knowledge by another. Examples are the licensing of technology or the decision to cooperate in a joint venture in which firms contribute know-how. It is a common feature that such agreements prohibit the selling of the technological rights to other firms, thus preventing undesired strategic short-cuts.

Property rights can particularly have a powerful effect on networks if the resource is scarce insofar that it constitutes a "bottleneck" technology, such as an operating system standard for software, or an electrical grid, or the telecommunication "pipe" to a residence. Possession of rights to a bottleneck resource can lead clearly to a monopoly position. However, it may also lead to isolation, rather than centrality, if a firm decides to exploit its position without cooperation. Hence cooperation is critical.

Cooperation is likely to result when a firm owns a scarce resource, and yet is competing against other firms who offer alternatives. These property rights to a bottleneck resource are especially valuable when coupled with "network externalities." These externalities arise when the consumption or use of a good by one person or firm makes it attractive to another to do the same —the classic example being a computer operating system. In these joint conditions of externalities in competitive environments, cooperation is encouraged.

Such externalities, for example, exist in microprocessors. Since software is written for microprocessor standards and people want to use the same software, there exist externalities that favor the dominance of one standard over another. For a microprocessor firm, the logical strategy is to grab the largest size of the market. Somewhat counter-intuitively, it would want to induce entry into its market as long as these entrants agreed to license its technology and standards. In fact, cooperation exploded in the microprocessor industry until Motorola and Intel achieved dominance; National Semiconductor did not achieve the same penetration and, interestingly, maintained a higher level of alliance activity. Because all entrants were required basically to cooperate on the standards, these three firms were each centered in the middle of a star of relationships. Centrality thus was the outcome of network externalities coupled with a strong property right regime.[13] Thus, in this case, the strategy to appropriate rents through technology licensing generated the structure, rather than structure simply determining the rents to a broker or Coleman group.

It is proverbially axiomatic that in a hub and spoke structure, such as associated with the dominance of Intel in microprocessor licensing, the central firm is in the better position to reap the rents in the network. (Think of this prediction as identical to the measure of market power by sales concentration.) Certainly, any bottleneck position should be associated with differential market power. The bottleneck could be property rights to the limited number of gates at an airport (which clearly is reflected in a "hub and spoke" transportation pattern), the communications pipeline to the home, water reservoirs in a desert, etc. All of these bottlenecks produce structural holes with the gains to the broker.

In many industries, property rights to bottlenecks are not a characteristic of the competitive

[13]This analysis is given in Kogut, Walter, and Kim (1996).

landscape. Firms would certainly benefit from trying to replicate the rent capture imposed through hierarchical dominance. And yet, the claim of Uzzi and others is that rent generation can be superior in a dense clique with thick ties among the players because of improved coordination and problem-solving. In such cases, the preservation of cooperation is maintained because exclusion to the club deprives the defecting member from sharing the group rents. (This sanctioning possibility is the basis of the Nash comparisons behind the Axelrod, et al., 1995, simulation discussed earlier.) In other words, rents to coordination again provide self-organizing incentives to members to maintain the network structure.

Table 1 summarizes the discussion of the relationship of network structure and property rights to bottleneck resources. The consequences for rent generation and distribution depend on the assessment of the viability of competing rules for cooperation. The empirical studies of various industries indicate that certain rules came to dominate, but in the context of particular historical and institutional settings. Thus, the rule for cooperation that appears to have proliferated in microprocessors is to share technology, while not giving up control to the bottleneck resource itself. In some industries where property rights are strong, but there is no bottleneck technology (e.g., in pharmaceuticals), the emergent structure does not consist of competition among a few hubs, but reveals a complex structure with many central firms and also many isolates. One surmises that in this industry, centrality might reflect the "quality" of a firm rather than its control over a brokerage position. This may be the reverse in the financial industry, where in fact the position in an information flow results in the capture of rents. Quality is an attribute of the position. While trading relationships are still embedded in structure (Baker, 1984), the incentives to cooperate are attentive to positions of prestige and rank. Here indeed we have Burt rents accruing to structural holes.

An interesting case is where property rights to a given scarce resource are not strong, but there still exists discernible structure among competing hubs. Automobile assembly is a good example, whereby assemblers have some power over access to distribution channels and customer loyalty but they do not have property right control over unique assembly skills. Indeed, entry by new companies has been an important element in the history of this industry.

The dependence of structure on historical and institutional conditions is also revealed in the variety of competing rules and their implications for the emergence of distinct network configurations. The evolution of the Toyota System illustrates precisely the migration from a hub-and-spoke structure to a more cooperative self-

Table 1. Competing rules and structural predictions (Ignoring social rules)

Regulatory	Technological	Feasible Structure	Industry Example	Competing Rules
1. Strong property rights	Bottleneck resource	Central players with no isolates	Microprocessors, software operating systems	Induce entry by licensing vs. dominate by superior technology
2. Strong property rights	No bottleneck resource	Weak hierarchies with many isolates	Pharmaceuticals	Cooperate for finance vs. dominate by superior technology
3. Weak property rights	Bottleneck resource	Many closed hierarchies with no isolates	Autos	Source widely while switching often vs. build competence in few single-source suppliers
4. Weak property rights	No bottleneck resource	Decentralized relational networks	Information and financial markets	Seek new information vs. rely on existing relationships

organizing supplier system because the generative rules of cooperation changed over time. Because the work on supplier chains in the automobile industry consists of a rich set of studies that highlight the creation of capabilities through networks, we use this industry in the following section to provide a holistic exploration of the ideas of organizing principles as generative rules and the relationship of emergent structure and rents.

An illustration: Toyota production system

The Toyota Production System constitutes one of the most important organizational innovations of recent decades, yet it did not emerge out of a conscious design but out of an emergent process (Fruin and Nishiguchi, 1993). The Japanese market consisted after the war of a demand for high variety, a plethora of auto companies none of which operated plants built to the scale of the mass production facilities of American companies. Furthermore, Japanese suppliers were initially inferior in their capabilities compared to assemblers (Nishiguchi, 1994). Over time, this 'dual labor market' evolved into a new division of labor based upon the continuous upgrading of supplier competence and their participation in project design. These new tight supplier relationships created capabilities that increased speed to market, quality, and new model cycle times, with supplier networks as the organizing principle to deliver this capability.

The inter-organizational model emerged in Japan during a period from 1965 to the early 1980s. Over this time period, the production structure shifted toward reciprocal, multilateral relations and a concern with specific rights of transaction rather than residual rights of ownership. From using subcontractors mainly as buffers in the 1950s, assemblers were after 1960 committed to upgrade their subcontractors' technical capabilities. The composite know-how of assemblers was transferred to suppliers through teaching, along with assembly lines. The emergence of contract assembly and subsystems manufacture noticeably changed the logic of supplier relations toward "collaborative manufacturing." There were obviously gains to both buyers and suppliers in the form of increased returns of higher order organizing principles.

Though historically emergent, the transfer of the Toyota Production System represents the efforts to transfer networks by design to other countries (Florida and Kenney, 1991; Dyer, 1996). However, the rules by which supplier networks emerged in Japan are different than the rules that guide its design and transfer. (Here again, we must separate out genesis from persistence.) In effect, the emergence of inter-supplier networks were guided by these two rules:

1. The dual labor market is not violated by integrating suppliers into Toyota.
2. Supplier capabilities are improved through the transfer of competence to them.

The first rule grew out of the recognized limits of a Japanese company toward extending the reciprocal agreements among employees to suppliers. Membership in a large company entailed expectations of long-term employment in return for strong identification of the employee with the firm. Contrary to Stigler's hypothesis of the integration of weak suppliers, the social expectations underlying the employment relationship precluded the integration of suppliers into the core firm.[14] The second rule developed partly as a consequence of the first, as well as through government policy to protect weaker suppliers against the dominance of large assemblers (Nishiguchi, 1994).

Many subcontractors welcomed the new subcontracting system, since it brought with it more stable contractual relations through increased asset specificity, more opportunities for technological learning, and improved growth prospects (Nishiguchi, 1994). From using subcontractors mainly as buffers in the 1950s, assemblers were after 1960 committed to upgrade their subcontractors' technical capabilities. The composite know-how of assemblers (including the know-how to operate assembly lines) was transferred to suppliers through teaching. The emergence of contract assembly and subsystems manufacture noticeably changed the logic of supplier relations toward "collaborative manufacturing." There were obviously gains to both buyers and suppliers in the form of increased returns of higher order organizing principles.

Still, these two rules generated initially a net-

[14]This relationship is described in many places, including Aoki (1990), Ablegglen and Stalk (1985), and Nischiguchi (1994).

work structure that was strikingly hierarchical in structure, creating a hub-and-spoke centrality around Toyota. In this regard, the Toyota supplier structure was organized along hierarchical lines that were not substantially different than those found among General Motors and its suppliers. However, the rule to respect the dual labor market prohibited the extensive vertical integration seen among American firms. Toyota's value added contribution to its autos was, and remains, radically less than General Motors' share of value in its assembled cars. (See also Dyer, 1996, who found the internal value-added of an American assembler to be twice that of a Japanese.)

The dynamic that transformed this hierarchy into a more closed relationship stemmed from the logic of a series of organizational and process innovations that began within Toyota and eventually diffused out to suppliers. The initial innovations of Toyota centered around the introduction of customer-driven production (kanban) manufacturing. The danger of this kind of production system is that working capital growth serves as the buffer to respond flexibly to changes in customer demand. Almost by contradiction, Toyota innovated by minimizing inventory levels through the innovation of just-in-time (JIT) deliveries. These systems were coupled with powerful analytical tools, such as value analysis and quality control, which generated information used to minimize costs.[15]

If kanban and JIT were powerful innovations, rapid introduction would appear to be fostered through vertical integration. In fact, through vertical integration, a firm should have more power to enact JIT because it has the authority to do so. Supplier resistance to these innovations clearly frustrated the chief architect of Toyota's innovations, Ono, who complained bitterly over the resistance to these new methods (Cusumano, 1985). Lieberman and Demeester (1999) document the slow diffusion of these methods by tracking inventory levels among suppliers, finding that they continue to decrease for Toyota suppliers through the 1970s, with Nissan and other Japanese firms lagging considerably.

The gradual extension of these new organizing principles of customer-driven production transformed supplier relations from the exploitation of subcontractors to collaborative manufacturing based on multilateral problem solving. Over time, asset-specific contractual relations increased, as exemplified by contract assemblers and system-component producers. Structurally, Japanese subcontractors were reorganized over time into tiers through a concentration of orders, intensified specialization, and increased dependence on particular customers (Fruin and Nishiguchi, 1993). In the new tightly tiered structure, approximately 180 first-tier suppliers contract to several thousand lower-tier subcontractors that, in turn, contract to tens of thousands third tier suppliers. This structure maintained variety in identity and competence among suppliers, while generating long-term coordination among the key participants in the Toyota System.

This tiered structure implies that at a given time, subcontracting philosophies at plants within the same firm vary widely. Nishiguchi compares philosophies within the same buyer firm, ranging from "bargaining" subcontractor managers who used subcontractors to protect regular workers when demand fluctuated to pro-subcontracting managers who engaged in intense contacts, training and problem solving. Nishiguchi's results are consistent with asset specificity not being the cause but the consequence of a particular strategy. (In fact, he finds asset specificity to be a consequence of the supply strategy.) Yet, at the same time, a strategy that points to asset-specific contractual relations needs inter-firm relational mechanisms that enable them to function.

The increased reliance by Toyota on first-tier suppliers generated important organizational innovations designed for the new network. Through repeated interaction between firms in the network, a series of innovations emerged that supported the acquisition of skills specific to the relationships, or what Asanuma (1989) has called 'relation-specific' capital. (See also Dyer, 1996, and Dyer and Singh, 1998, for an exposition of this idea.) These innovations included joint price determination based on objective value analysis, joint design based on value engineering, the target cost method of product development, profit-sharing rules, subcontractor proposals, black box design, resident engineers, subcontractor grading, quality assurance through self-certified subcontractors, and just-in-time delivery circumscribed by bonus-penalty programs. These innovations represented the shift from main purchasing func-

[15] Ohmae's (1982) early study is a brilliant explanation of the strategic implications of value analysis of Japanese firms.

tion of the customer shifted from downstream price negotiation to the assessment of subcontractor performance and the coordination of interfirm functions.

Asanuma's description of the heterogeneity of the Toyota supplier system indicates a network in which a set of tiered suppliers acts to differentiate the status of suppliers. An important distinction is between suppliers that work according to drawings supplied by the core firm, and those that submit their own drawings to the core firm for approval. Over time, the latter groups of more innovative suppliers evolve toward greater independence because of an increase in volume produced by a supplier, or an increase in the scope of activities performed by a supplier.

Through monitoring and supplier qualification requirements, the core plant selectively develops relationships with suppliers. Suppliers are evaluated according to how well they have performed on earlier contracts. Often partial ownership is sought in the suppliers that rank the highest in terms of performance and potential capabilities. Moreover, suppliers earn points in the supplier rating system for codifying methods so that they can be used by other suppliers, leading to lower costs for the core firm. By this dynamic, continuous learning lead to improvement in productivity of the whole supplier networks. All types of suppliers had to develop some skills to maintain the relation to the core firm, other than purely technological capabilities.

In effect, Toyota evolved a system that relied upon self-organization to resolve the contradiction between its two rules: the inability to integrate while requiring improvement in supplier skills. The tiered system forced firms to prove their competence and yet also created incentives for them to codify and share their knowledge. Thus, the first two rules were augmented by a third:

3. To participate in the first tier, suppliers are required to prove, codify, and share their competence with each other.

Unlike the operation of the competitive hierarchy to American assemblers, this hierarchy then evolved to move the single locus of innovation from the core assembler (Toyota) to the suppliers as well. Nishiguchi (1994) calls this "clustered control"; in our terminology, it represents a Coleman network of dense ties between the members.

This structure achieved "independent viability" in Coleman's terms by devising rent-sharing rules that supported decentralized innovations. Initial prices are set in the light of planned production costs, based on the supplier's and the core firm's experience with similar parts. It clearly recognizes the firm as the "unit of accrual" and structures decentralized incentives to promote coordination. If the supplier should improve the process and outpace the planned experience-derived cost reductions, it retains the savings. The pricing mechanism reflects not only an anticipation of learning on the part of the suppliers; it provides an incentive to beat the target. However, at the same time, rule three dictates that these improvements flow to other suppliers. As a consequence, improvements at one supplier flow dynamically to others.

Independent viability of membership is a necessary factor in the self-organizing character to the Toyota Supply system.[16] Consider a firm that withheld technology and sought to free-ride on the efforts of others. The intense information flows permit easy monitoring; sanctions need be no more than exclusion from the first-tier club that shares rents. No wonder in times of crisis, cooperation can be organized without hierarchical control, a key attribute of a self-organizing system. (See Nishiguchi and Beaudet, 1998, for a discussion of self-organization following a fire at a top-tier supplier.) It is important to observe that this system, from the point of view of Toyota, represents a less costly expenditure of time even if it involves a dense set of ties. Because monitoring is coupled with cooperation in technology transfer, it is also occasion to learn from other supplier's experiences (see Sabel, 1996; Helper, MacDuffie, and Sabel, 1998).

Dense networks provide an important capability of knowledge acquisition, in conjunction with also generating information required for monitoring and enforcement. Thus, monitoring occurs not as a function of an overt sanction mechanism, but rather through the operation of professional identities that support the transfer of technology

[16]This viability is similar to Axelrod et al.'s (1995) imposition of Nash equilibrium: firms do not switch coalitions if the change does not improve their utility. Of course, firms might want to switch into a Toyota coalition and free-ride; hence the importance of the third screening rule.

among suppliers and Toyota.[17] Whereas a brokerage role is efficient from the perspective of monitoring and sanctioning, the self-organizing properties of dense relationships benefits from putting the stress on the rapid flow of competencies through frequent and on-going relationships.

The organizing principles of the Toyota System support the capabilities of providing variety and speed to the market. Capable suppliers in a network provide competing variety based upon specialized competence. Black box modularity permits specialization, and yet demands a high degree of coordination. The rapid diffusion of production know how serves to reduce the costs, while the tight coordination of suppliers and assembly in design and production reduces overall time to the market.

These capabilities did not reside in any given firm, but were created by the knowledge of how to coordinate among firms with a history of cooperation. The unit of accrual is the individual firm; there is no holding company structure to the network. Yet, to remove a firm from this network would be to deprive it of important capabilities that it could not immediately recreate, even if it could access equally capable suppliers. These capabilities are not simply the static ones of reducing inventory, but of encouraging innovations by technology transfer and incentives.

The Toyota System thus created a structure in which variety could be maintained among strong suppliers without disrupting the centrality of the assembler in the system. Toyota thus did not fall prey to Stigler's solution of vertical integration to overcome inefficiencies in the network. However, each firm remained the unit of accrual. These adaptive innovations, thus, posed the Williamson problem that property claims to this knowledge were weak, hence creating the incentive for suppliers to maintain secrecy. These threats were resolved, though, by three mechanisms. Coordination generated rents that induce cooperation by acting as an bond or efficiency wage to deter defection; defection would lead to deprivation from future rents. Second, the process of technology transfer itself created information that enabled monitoring within the network as opposed as through hierarchical control. But there is also a third mechanism, the value of enhance coordination through the identity of members in the high status Toyota Production system.

The Toyota system embodies the irony that these principles of coordination arose due to restrictions on vertical integration. But if the emergence of the Toyota network could not have been foreseen, its transfer by replication in the United States and elsewhere entails intentional coordination among network members. Yet, these intentions do necessarily demand authority to insure replication. Toyota does not need to order its American suppliers: create the Toyota Production System by this blueprint. Replication need not follow a description of who cooperates with whom and how. For the incentives to replicate implies the possession of capabilities that are rent generating, hence rewarding members to re-create the structure. While the origins of the Toyota System suggest the operation of unintended consequences in the evolution of the network, the intentional adherence to these rules suggests a functional understanding of their causal consequences.

CONCLUSIONS

We began with the observation that value is not a mystical entity. The source of its imputation is not always clear, as witnessed in the lack of consensus over the interpretation of a residual, called total factor productivity. In recent years, we have come to understand better that an important source of value for a firm lies in the capabilities supported by organizing principles of work. These principles constitute what is meant as the knowledge of the firm.

The study of networks as knowledge understands capabilities achieved through coordinated action at multiple levels of analysis. At one level, knowledge is the principles defining coordination in a division of labor that anchor identities of individuals and groups within firms. At another level, the boundary of firm and network are malleable definitions determined by shifting identities and their co-evolving capabilities. Operating upon these levels is the domain of generative rules of cooperation and competition.

The network generated by rules of cooperation differentiates firms by their structural positions. Since firms but not networks are units of accrual

[17]It is not surprising that suppliers are often conflicted in their loyalties, especially at times when these networks are transferred to new locations.

and selection, there exists, therefore, a potential divergence between the distribution of these rents and the contribution of individual firms. Sometimes, this divergence is mitigated through the coincidence of structural position and property right claims. However, in situations in which knowledge is diffuse among a group of firms, coordination can become prey to concerns over cooperation. Embedding a monitoring and sanction mechanism into a cycle of positive returns attached to technology transfer drove the particular success of the supplier system of the Toyota Production System. And by devising credible rules that guaranteed independent viability, Toyota could, by intention, replicate the network (even if particular members changed) in new locations.

Networks are more than just relationships that govern the diffusion of innovations and norms, or explain the variability of access to information across competing firms. Because they are the outcome of generative rules of coordination, networks constitute capabilities that augment the value of firms. These capabilities, e.g., speed to market, generate rents that are subject to private appropriation. It is through an understanding of networks as knowledge encoding coordination within and between specialized firms in specific cooperative and competitive structures that the "missing" sources of value can be found.

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