Capabilities and Vertical Disintegration in Process Technology: The Case of Semiconductor Fabrication Equipment.

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ABSTRACT

This paper presents a detailed case study of the cluster-tool segment of the American semiconductor-equipment industry. That industry has embarked upon a technological trajectory in which cluster-tool components (or modules) conform to a set of common interface standards. Cluster tools are thus becoming a *modular system* in the manner of an IBM-compatible personal computer or a stereo system. Such standards permit the sharing and reuse of technological capabilities, leading to what one might call *external economies of scope*. These reduce the need for and the benefits of large size and systemic coordination, permitting firms to concentrate their capabilities narrowly and deeply on a small range of components.

The paper outlines the theory of modular systems; discusses the economics of single-wafer processing in general and cluster tools in particular; recounts the history of standard-setting in the industry; and examines ongoing issues of strategy and market structure. One conclusion of this analysis is that standard-setting may in this case blunt the widely touted benefits of the “Japanese model” of manufacturer-supplier relations. The public knowledge contained in common interface standards serves as a partial substitute for the detailed coordination and long-term relationships that model holds to be the hallmark of Japanese firms, thus shifting advantage in the direction of a loose network of small vertically and laterally specialized firms.

Introduction.

Alfred Chandler's influential book *Scale and Scope* (1991) has added new weight to the Schumpeterian proposition that the large vertically integrated firm was at the vanguard of economic growth in the late nineteenth and early twentieth centuries (Schumpeter 1950, p. 82). A number of writers have taken the message of Schumpeter and Chandler to be that economic capabilities are always best created within the framework of large firms enjoying internal economies of scale and scope; as a consequence, industrial competitiveness depends crucially — and perhaps even exclusively — on fostering internal capabilities. For a time at least, this argument found special application in the arena of high technology, including semiconductors. Until recently, it was common to hear that the decentralized, entrepreneurial American industry ultimately would prove no match for the large firms of Asia, and that the United States must somehow consolidate and bolster the internal capabilities of its firms, with government help if necessary (Florida and Kenney 1990; Ferguson 1985, 1990).

There is certainly much wisdom in the Schumpeter-Chandler view, especially as an antidote to the naive adulation paid to the model of atomistic competition in neoclassical theory and policy. Nonetheless, there is reason to think that an overemphasis on the internal creation and management of economic capabilities can be equally unhealthy. Networks of decentralized firms, including those networks often derogated as “markets,” can also be repositories and generators of economic capabilities. To insist on vertical integration — or, for that matter, on agglomerations of small “flexibly specialized” producers (Piore and Sabel 1984; Best 1990) — as a universal prescription misses the subtlety and historical idiosyncrasy of industrial evolution (Langlois and Robertson 1995).

A crucial issue in the comparison among the institutions of industrial organization is the ability of those institutions to generate technological progress. At the risk of oversimplifying matters somewhat, we might say that the relative merits of firms and networks hinge on whether innovation is *systemic* or *autonomous* (Teece 1986). When innovation is systemic, there is reason to think that a firm-like structure will prove more conducive to rapid technological progress. This is so because systemic innovation requires simultaneous change in many different stages of production, and common ownership of complementary stages lowers the transaction costs of persuasion and coordination (Silver 1984; Langlois and Robertson 1995). By contrast, there is reason to think that networks — including archetypical "markets" as one extreme — may have advantages when innovation is *autonomous*, that is, when technological change in one stage of production can proceed without requiring corresponding changes in other parts of the system. In this case, the advantages of the firm in persuasion and coordination are outweighed by Smithian economies of specialization and by the ability of networks to access a larger and more diverse pool of relevant capabilities (Langlois 1992; Langlois and Robertson 1992).

But the systemic or autonomous nature of innovation is neither entirely exogenous nor driven solely by technology. The structure of organization helps shape the pattern of innovation, which in turn influences the subsequent structure of organization. In short, a theory of organizational structure is properly part of an evolutionary theory of social institutions (Langlois 1993). A clear manifestation of this is the importance of one particular kind of social institution — namely, standards — for both innovation and industrial structure.[1] In the absence of shared conventions to demarcate the boundaries between and standardize the connections among stages of production, autonomous innovation is costly. As a result, competitive advantage may go to organizations with significant internal capabilities for systemic innovation. This would imply competition among individualized pre-packaged entities — what we can call closed proprietary systems. Automobiles would be an example: each car manufacturer chooses the attributes

[1] See, for example, Kindleberger (1983) on standards as a social institution.

of a car, assembles it, and offers it to the public as a package. If common standards do appear, however, products may become what Langlois and Robertson (1992) call *modular systems*. (Imagine being able cheaply to assemble an automobile at home from a catalogue of interchangeable bumpers, fenders, engines, etc.) In the case of a modular system, competition among prepackaged entities gives way to competition among the producers of compatible modular components. This tends to favor networks at the system level, even if the various modules themselves are (internally) closed proprietary systems produced by what may be vertically integrated firms. Prominent examples of modular systems are IBM-compatible personal computers and high-fidelity audio systems (Langlois and Robertson 1992; Robertson and Langlois 1992).

In view of the costs of collective action involved in the setting of standards, the frequent emergence of such standards suggests that modular systems can offer net benefits over the closed proprietary alternative. These benefits come on both the demand side and the supply side. One effect of standard "interfaces" among components is to lower the costs of assembly, both by lowering transaction costs and by reducing the optimal scale of the assembly function. As a result, assemblers (who may be the system users themselves in some cases) can more cheaply tailor a system to the user's exact requirements. On the supply side, modular systems can lower production costs by enlisting specialization in the cause of innovation. More importantly, modularity breaks the barrier of the boundaries of the firm, bringing to bear both a larger volume and a wider diversity of capabilities than even the largest of organizations could cheaply marshal.

We can think of the role of standards in terms of economies of scope. Following in the tradition of Edith Penrose (1959), Teece (1980, 1982) has argued that economies of scope arise when an organization has excess capabilities that can usefully be applied to activities similar to the ones in which it is all ready engaged. To the extent, for example, that a software firm reuses pieces of existing code in writing new packages, it partakes of

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