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Persistence of Integration in the Face of Specialization: How Firms Navigated the Winds of Disintegration and Shaped the Architecture of the Semiconductor Industry

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Although the stylized model of industry evolution suggests that firms transform from vertical integration to specialization over time, many industries still exhibit a continued persistence of integrated firms. In exploring this puzzle, I draw on detailed firm-level data from the semiconductor industry to analyze how integrated incumbents, beyond shifting to the specialized mode, reconfigured in the face of industry's vertical disintegration so as to coexist with the specialized firms. I propose and find that the incumbents who persist with vertical integration increase their emphasis on systemic innovations and transact with specialized firms in both upstream and intermediate markets. The value-creating opportunities associated with integrated incumbents' leveraging (a) their relative superiority in developing systemic innovations and (b) markets to pursue a broader menu of transactional choices may offset their costs of staying integrated. These firm-level factors also determine the pattern of industry's vertical disintegration and the extent of coexistence between integrated and specialized firms.

Key words: firm boundaries; vertical integration; industry evolution; organizational adaptation; semiconductor industry
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Introduction

The evolution of an industry's vertical structure over its life cycle has been an important line of inquiry for management scholars. A stylized pattern that scholars have sought to explain is that many industries are initially dominated by vertically integrated firms, and over time, they transform into a vertically specialized structure with new entrants that specialize in a specific stage of production entering the industry and with integrated incumbents exiting or shifting to the specialized mode. This transformation has been attributed to increasing returns to scale as demand grows (Stigler 1951, Klepper 1997), modularization of products and processes to manage technological complexity and user heterogeneity (Baldwin and Clark 2000, Schilling 2000, Langlois 2003), and the evolution of capabilities and transaction costs along the value chain (Jacobides and Winter 2005, Malerba et al. 2008).

Although great progress has been made in our understanding of why industries become more specialized over time, the inquiry within the literature has predominantly focused on the evolutionary processes underlying the industry's vertical specialization. Scholars have thus either implicitly or explicitly implied that integrated incumbents must conform to the specialized mode as industries mature or risk inferior performance and industry failure (e.g., Langlois 1992, Langlois and Robertson 1992, Christensen 1993, Fine 1998, Sturgeon 2002, Jacobides 2005). This is at odds with evidence from a number of industries in which integrated firms continue to persist despite a trend toward vertical specialization (Argyres and Bigelow 2010, Helfat and Campo-Rembado 2010, Kapoor and Adner 2012). In this study, I attempt to reconcile this dominant paradigm in the industry evolution literature (i.e., shift from integration to specialization) with recent evidence on the coexistence of two organizational forms by exploring the following research question: *Beyond shifting to the specialized mode, how might integrated incumbents reconfigure their activities in the face of the industry's vertical disintegration?*

The exploration of this question complements existing studies that have emphasized how different types of evolutionary processes shape the industry's vertical structure and integrated incumbents' performance outcomes (e.g., Langlois 1992, Christensen 1993, Afuah 2001, Malerba et al. 2008) with an explicit account of how integrated incumbents adapt in the face of the industry's vertical disintegration. Hence, rather than focusing on the industry-level selection pressures, this study jointly considers the processes of selection with those of firm-level adaptation (e.g., Singh et al. 1986, Levinthal 1997) to explain the coexistence of integrated and specialized firms in the context of the industry's evolution.

I draw on the firm boundaries literature rooted in transaction cost economics, capabilities-based, and modularity theories to identify the menu of reconfiguration options that integrated firms may face as industries become more specialized. These options, which include different types of innovations and transactional choices, represent important reconfiguration possibilities for integrated firms so as to differentiate from specialized firms and to utilize the new opportunities presented by the emerging industry structure. I distinguish between systemic innovations requiring extensive coordination and communication across different stages of production and those that are autonomous, which can be introduced without significant adjustment or modification to other stages of production (Teece 1984, 1996). I consider the relative advantage that integrated firms enjoy in competing through systemic innovations (Christensen et al. 2002, Fixson and Park 2008, Kapoor and Adner 2012) and the relative superiority of systemic innovations in deterring imitation and sustaining competitive advantage (Pil and Cohen 2006, Ethiraj et al. 2008). Furthermore, beyond the traditional make-or-buy choice emphasized by the extant literature on industry evolution, I also consider transactional choices that would allow integrated firms to generate supply-side efficiencies by leveraging markets while staying integrated. Such choices include make and buy as well as participation in intermediate markets by selling to specialized firms (Harrigan 1984, Jacobides and Billinger 2006, Rothaermel et al. 2006, Parmigiani 2007, Luo et al. 2012). I argue that the persistence of integrated incumbents in the face of industry's vertical disintegration would be associated with integrated firms increasing their emphasis on systemic innovations as well as transacting with specialized firms in both upstream and intermediate markets.

The arguments are explored in the context of the global semiconductor industry. Since the 1980s, the industry has been subjected to the process of vertical disintegration because of the entry of specialized "fabless" firms who design and sell semiconductor chips but, unlike integrated incumbents, rely on external suppliers for manufacturing (e.g., Macher et al. 1998, Hall and Ziedonis 2001, Strojvas 2005). Despite a significant rise in the number of specialized firms, a majority of integrated incumbents have persisted for over two decades without conforming to the specialized mode of organization. I draw on detailed firm-level data to analyze the response of integrated incumbents as the industry transitioned toward greater specialization. I find that integrated firms, in the face of industry's vertical disintegration, shifted their innovation activities toward systemic innovations involving novel combinations of design and manufacturing tasks. I also find that instead of becoming specialized, incumbents reconfigured their boundaries so as to benefit from transacting with specialized firms in both upstream and intermediate markets while remaining integrated.

The study, although specific to a single industry, helps to inform the stylized model of industry evolution (i.e., shift from integration to specialization) with an explicit consideration of the coexistence of the two organizational forms. Rather than the integrated organizational form being "creatively destroyed" by the specialized form, the study sheds light on the specific mechanisms that may allow integrated firms to coexist with the specialized firms. By increasing their emphasis on systemic innovations, and by transacting with specialized firms in upstream and intermediate markets, integrated incumbents can differentiate from specialized firms and yet benefit from the existence of markets for upstream and intermediate activities. The findings from the study argue for a simple yet generalizable theoretical framework to explain the pattern of industry's vertical disintegration. It suggests that as an industry transitions from an integrated to a specialized structure, there is a change in the distribution of capabilities among industry participants. This change presents new value-creating opportunities for integrated incumbents that entail leveraging their relative superiority in developing systemic innovations over specialized firms, as well as leveraging the markets to pursue a broader menu of transactional choices. The extent to which these opportunities offset firms' costs of staying integrated will determine the pattern of industry's vertical disintegration and the extent of coexistence between integrated and specialized firms.

The findings also complement studies examining how transaction cost alignment (i.e., the choice of governance mode as prescribed by transaction cost economics) affects firm performance during significant industry change (e.g., Nickerson and Silverman 2003, Argyres and Bigelow 2007). Whereas these examinations argue for firms to change their governance mode as industry evolves, the case of the semiconductor industry presents an alternative account of how firms can learn and more efficiently manage their preexisting governance mode in response to industry change (Argyres 2011).

In the next section, I provide a brief overview of the literature on industry evolution and vertical integration, and I identify some of the gaps in the literature that this study seeks to address. I then present my arguments regarding how integrated firms may respond to the industry's vertical disintegration so as to coexist with the specialized firms. This is followed by a detailed account of the vertical disintegration of the global semiconductor industry and how integrated incumbents have responded to shifts in the industry's vertical structure. I conclude by discussing the study's contributions, limitations, and avenues for future research.

Industry Evolution and Vertical Integration

The link between industry evolution and vertical integration has long been of interest to scholars in economics and management. The most noticeable early effort included Stigler's (1951) proposition that industries will be initially populated by vertically integrated firms. As the demand for the new product grows, it becomes profitable for specialized firms to carry out functions that exhibit increasing returns to scale (Smith 1776). This pattern will eventually reverse during the declining stage of the industry, when the smaller size of the market will make it inefficient for activities to be carried out by specialized firms. Although the validity of Stigler's theory has been questioned on a number of grounds (e.g., Chandler 1977, Williamson 1985, Langlois and Robertson 1995, Klepper 1997, Bresnahan and Gambardella 1998), the evolutionary shift from vertical integration to specialization has been documented in a wide array of industries. These include textiles (Gibb 1950), machine tools (Rosenberg 1963), commercial aircraft (Mowery and Rosenberg 1982), personal computers (Baldwin and Clark 2000), stereos (Langlois and Robertson 1992), disk drives (Christensen 1993), software (Steinmueller 1996), chemicals (Arora and Gambardella 1998), and mortgage banking (Jacobides 2005). Furthermore, across 33 industries, Agarwal (1997) documents the reversal of survival advantages that accrue to integrated firms relative to specialized firms as industries evolve.

In developing a better understanding of the drivers of industry's vertical disintegration, scholars have identified a range of evolutionary mechanisms that are not necessarily mutually exclusive. Baldwin and Clark (2000), Schilling (2000), and Langlois (2003) attribute the vertical specialization of the industry to the modularization of products and processes so as to manage greater technological complexity and provide heterogeneous users with greater flexibility to mix and match modules. As products and processes become modularized, it becomes easier for activities to be coordinated via markets, which results in industries being populated by specialized firms. Qian et al. (2012) consider the value chain choices of industry entrants and show that the entrant's decision to vertically specialize is affected by transient transaction costs, which relates to reduction in asset specificity and uncertainty over the industry life cycle. Lamoreaux et al. (2003) attribute vertical specialization to the reduction in transportation and communication costs allowing for specialized firms to coordinate activities through long-term relationships. Jacobides and Winter (2005) integrate arguments from evolutionary economics, transaction cost economics, and the resource-based view to explain the evolution of an industry's vertical structure over its life cycle. Their framework considers intertemporal shifts in the distribution of capabilities and transaction costs governed by industry-level selection processes and past firm-level choices. In doing so, they not only explain the typical shift from vertical integration to disintegration (e.g., U.S. mortgage banking industry) but also explain the shift from specialization to reintegration observed in some industries that is brought about by technology discontinuities (e.g., Swiss watch manufacturing). Similarly, Malerba et al. (2008) consider the evolution of firm capabilities and technology discontinuities to develop a "history-friendly" model and explain the pattern of vertical integration observed in the U.S. computer industry between the early 1950s and the mid-1980s.

A noticeable feature of this literature has been an explicit focus on explaining the rise of the specialized form and, in some cases, a sequential shift between integrated and specialized forms punctuated by technology discontinuities. The theoretical explanations that are offered and the empirical examinations that are carried out suggest that a specific form of an organization (integrated or specialized) dominates at a specific stage in an industry's evolution (e.g., Langlois 1992, Langlois and Robertson 1992, Christensen 1993, Afuah 2001, Jacobides 2005). Hence, the literature has tended to link the evolutionary processes operating in a given industry to the corresponding dominance of a specific form of organization—integrated or specialized. This approach is incomplete for at least three reasons.

First, it is inconsistent with the fact that many industries are characterized by the coexistence of both vertically integrated and specialized firms over extended periods of time (Argyres and Bigelow 2010, Colfer and Baldwin 2010, Helfat and Campo-Rembado 2010, Kapoor and Adner 2012). Christensen et al. (2002) and Argyres and Bigeow (2010) have argued and provided evidence that integrated and specialized firms can coexist in the same industry by pursuing distinct competitive positions that focus on either low cost or product differentiation. Ganco and Agarwal (2009) and Qian et al. (2012) show how this coexistence can also be explained by differences in the firms' preentry capabilities. Another complementary explanation has been provided by Helfat and Campo-Rembado (2010), who theorize that in industries characterized by successive technology life cycles, integrated incumbents may continue to coexist with specialized firms in order to maintain their integrative capabilities for developing systemic innovations in the future (Teece 1996).[1]

Second, by suggesting that industries shift from integration to specialization, the literature has implicitly constrained the set of transactional choices faced by firms to either make or buy. This is at odds with the evidence from a variety of industries that firms often pursue a broader set of transactional choices than make or buy. For example, firms have been shown to pursue both make and buy (e.g., Harrigan 1985, Rothaermel et al. 2006, Parmigiani 2007). Beyond make and buy, firms have also been shown to participate in intermediate product markets by supplying an upstream good or service to external buyers in addition to internal consumption (Jacobides and Billinger 2006, Luo et al. 2012).[2]

Finally, by suggesting that integrated incumbents either conform to a specialized organizational mode as industry evolves or risk inferior performance, the literature on industry evolution overlooks one of the important tenets of the field of strategic management: that the sustainability of a firm's competitive advantage depends on its ability to adapt to changes in the industry in ways that build on its distinctive strengths and capitalize on new opportunities (Teece et al. 1997). Conforming to a specialized mode in the face of industry disintegration will likely provide incumbents with competitive parity, rather than competitive advantage. Moreover, initiatives aimed at specialization may face unexpected organizational and technological constraints (MacDuffie 2013). Hence, beyond conformance, incumbents may pursue other strategic reconfigurations in the face of an industry's vertical disintegration that would allow them to leverage their existing resources and capabilities and sustain their competitive advantage (Agarwal and Helfat 2009).

In summary, although great progress has been made in understanding the mechanisms that underlie the shift in the vertical structure of industries, the literature has predominantly emphasized how different types of industry-level evolutionary processes shape the substitution of the integrated form, by the specialized form, or vice versa. The fact that many industries are populated by both integrated and specialized firms over extended periods of time and that the firm's menu of transactional choices is broader than the make-or-buy choice suggests that the extant literature has a fairly limited reach in explaining how firm strategies and industry evolution interact to shape industry's vertical structure.

In attempting to fill this gap, I consider the possibility that integrated incumbents in the face of industry's specialization may adapt and pursue a more extensive reconfiguration menu than what the extant literature on industry evolution seems to suggest (i.e., shifting to the specialized organizational form). Hence, instead of linking industry-level selection pressures to the dominance of a given organizational form, I consider the interaction between the processes of selection with those of firm-level adaptation to explain the persistence of integration in the face of specialization. I draw on the extant literature on firm boundaries to identify the potential reconfiguration possibilities that I argue could allow integrated incumbents to achieve a better fit with the new environment and explain their coexistence with the specialized firms.

Incumbents' Strategic Reconfiguration in the Face of Industry's Vertical Specialization

The transformation of an industry presents incumbents with both threats and opportunities. Managing the threats and exploiting the opportunities by adapting and replacing firms' products, activities, assets, and capabilities is critical to successful strategic reconfiguration (Eisenhardt and Martin 2000, Agarwal and Helfat 2009). In the context of an industry's vertical disintegration, integrated incumbents are threatened by specialized rivals who, by focusing on a narrower range of activities, incur reduced investments in research and development (R&D) and manufacturing as well as draw on a broader set of external capabilities (e.g., Langlois 1992, Sturgeon 2002). The use of markets to coordinate interdependent activities also allows specialized firms to mitigate low-powered incentives of the hierarchies and encourage greater effort by employees and organizational units (e.g., Williamson 1985, Mahoney 1992).

Scholars drawing on transaction cost economics and modularity theories have argued that specialized organizational forms are, in general, well suited for competing through autonomous innovations (e.g., Teece 1984, 1996; Langlois and Robertson 1995; Sanchez and Mahoney 1996; Baldwin and Clark 2000; Baldwin 2008; Hoetker 2006). Such innovations, often guided by industry standards and well-specified design rules, can be developed relatively independently without requiring significant adjustments in other stages of production. However, specialized firms are, in general, constrained in their ability to develop systemic innovations that require extensive coordination and communication across interdependent stages of production (Langlois and Robertson 1995, Teece 1996, Kapoor and Adner 2012).[3] Whereas alliances or research consortia may present alternative collaborative modes for specialized firms to pursue systemic innovations, such organizational arrangements are unlikely to match the extensive knowledge sharing and coordination of interdependent tasks enabled by the integrated organization (Teece 1984, 1996). For example, SEMATECH, an industry research consortium created to develop advanced semiconductor manufacturing technology, had to abandon its original mission because of the appropriability concerns and divergent objectives of the member firms, making these firms reluctant to share information and cooperate with each other (Grindley et al. 1994).

The high dependence on autonomous innovations presents specialized firms with at least two distinct competitive challenges. First, systemic innovations, by relaxing the constraints imposed by standardized interfaces and design rules, can provide users with superior technical performance (Ulrich 1995, Teece 1996, Christensen et al. 2002, Fixson and Park 2008). Hence, specialized firms may be hindered in their ability to compete at the technology frontier (Kapoor and Adner 2012). Second, autonomous innovations are highly susceptible to rivals' imitation efforts, thus making it difficult for specialized firms to sustain their competitive advantage over time (Pil and Cohen 2006, Ethiraj et al. 2008).

These challenges faced by specialized firms can offer opportunities for integrated firms. Instead of shifting to a specialized form, integrated firms can choose to differentiate from their specialized rivals by leveraging their relative superiority in developing systemic innovations. For example, they can pursue market applications that are underserved and use systemic innovations to create a competitive advantage over their specialized rivals (Christensen et al. 2002). Fixson and Park (2008) describe how Shimano persisted with a vertical integration strategy in the bicycle drivetrain industry and deliberately introduced systemic innovations that offered mountain bike riders superior performance. Greater complexity underlying systemic innovations also raises barriers to imitation (Rivkin 2000). Hence, an increase in emphasis on systemic innovations would also deter imitation efforts by specialized rivals and help integrated firms sustain their competitive advantage (Ethiraj et al. 2008). The above arguments suggest that integrated incumbents in the face of the industry's vertical disintegration may, instead of becoming specialized, reconfigure their innovation activities by shifting toward systemic innovations and coexist with specialized firms.

Proposition 1. *The coexistence of integrated and specialized firms in the face of industry's vertical disintegration will be associated with integrated firms increasing their emphasis on systemic innovations.*

The vertical specialization of the industry could also offer integrated incumbents other strategic opportunities for creating value. Instead of viewing their transactional choices as either make (stay integrated) or buy (become specialized), integrated firms can view them as an opportunity to both make and buy. The make-and-buy approach offers a number of advantages to integrated incumbents over the make-only approach. It provides firms with strategic flexibility and mitigates the risk associated with excess capacity especially in industries with high demand uncertainty (Harrigan 1985). It also allows firms to leverage their own and suppliers' differential capabilities and to learn from external suppliers (Jacobides and Hitt 2005, Parmigiani 2007). Compared with the buy-only approach, the make-and-buy approach enables firms to understand and coordinate external activities, and increase their bargaining power over suppliers (Heide 2003, Parmigiani 2007). Retaining in-house activities also allows firms to mitigate future transactional hazards (Langlois 1992).

Beyond make and buy, the emergence of specialized firms can also provide integrated firms with an opportunity to participate in intermediate product markets by supplying an upstream good or service to external buyers in addition to internal consumption (Jacobides and Billinger 2006, Luo et al. 2012). Greater demand for the upstream activity can help integrated firms realize economies of scale, especially when such activities entail significant investments. It also helps integrated firms mitigate organizational inefficiencies associated with the low-powered incentives of hierarchies and ensure that the upstream unit stays competitive.

Jacobides and Billinger (2006) explore this broad menu of transactional choices through their case study of a major European apparel firm. They found that the focal firm, rather than considering a simple make-or-buy choice, successfully pursued a "permeable" vertical structure that encompassed using internal and external suppliers as well as participating in intermediate and final product markets. Luo et al. (2012) document the existence of similar vertical permeable structures in the Japanese electronics industry.

Hence, instead of shifting from make to buy, the specialization of an industry can offer new efficiency-enhancing opportunities for integrated firms that involve transacting with specialized firms in both upstream and intermediate markets while staying integrated.

Proposition 2. *The coexistence of integrated and specialized firms in the face of industry's vertical disintegration will be associated with integrated firms transacting with specialized firms in upstream and intermediate markets.*

Data Sources

These arguments are explored in the context of the global semiconductor industry. The data for the study were collected using a variety of archival sources. I first obtained a list of all publicly traded semiconductor firms that competed in the industry between 1990 and 2008 from the Global Semiconductor Alliance (GSA), a trade association responsible for the collection and dissemination of industry data.[4] A useful feature of the GSA database is that it categorizes firms according to whether they are vertically integrated or specialized. I then retrieved information on these firms' patent grants, financial performance, and manufacturing activities. The data on patent grants were obtained from the Derwent World Patents Index database. There are several advantages of using Derwent for the purpose of this study. First, given the truly global nature of the semiconductor industry, Derwent provides a worldwide coverage of patent grants issued to semiconductor firms. Second, the database accounts for the fact that firms may seek patent protection for the same invention in multiple jurisdictions and may have subsequent revisions to the original patent. A single patent record in the database (labeled as patent family) often combines multiple patents related to the same invention. Third, Derwent has developed a proprietary patent technology classification system that allows for a more effective identification of patents based on the function or the application domain that the invention corresponds to (see Cockburn et al. 2000, Ziedonis 2004, Alcácer and Zhao 2012). This allowed me to characterize patents by semiconductor design and manufacturing, and it allowed me to analyze differences among firms' innovation activities. The data on firms' financial performance were retrieved from COMPUSTAT. Finally, information on firms' manufacturing activities was obtained from the World Fab Watch database maintained by SEMI™ and supplemented by firms' annual reports and press releases. I also conducted a number of interviews with industry executives that enabled me to corroborate my findings and discuss their implications.

Vertical Disintegration in the Semiconductor Industry

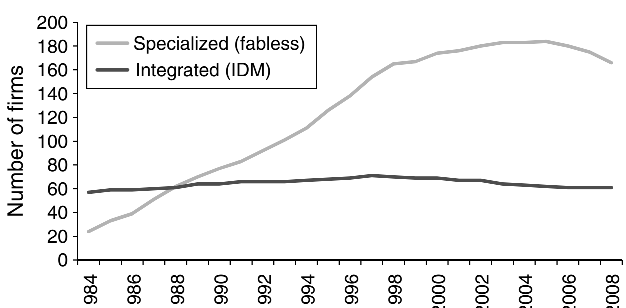
The semiconductor industry has its origins dating back to the 1950s. Since the 1980s, the industry has undergone a process of vertical disintegration spurred by the entry of a large number of specialized fabless firms who design and sell semiconductor chips but, unlike vertically integrated incumbents, rely on external suppliers for manufacturing (Monteverde 1995, Macher et al. 1998, Hall and Ziedonis 2001). The vertical disintegration of the semiconductor industry has been attributed to several supply-side and demand-side factors (Macher and Mowery 2004). First, significant increases in the demand for a variety of semiconductor products made specialization economically attractive, as specialized firms could derive economies of scale from their investments in the individual stages of production (Stigler 1951). Second, maintaining the trajectory of progress characterized by Moore's law required large recurring capital investments in R&D and manufacturing, thus raising the barriers to entry for firms pursuing integrated strategies. Third, the standardization of manufacturing processes based on complementary metal-oxide-semiconductor circuits facilitated the creation of markets for manufacturing, and it enabled specialized manufacturing suppliers (foundries) to offer the same manufacturing process to a large number of fabless firms. Finally, improvements in electronic design automation software further facilitated the decoupling of the design-manufacturing interface by allowing designers to incorporate detailed capabilities of the manufacturing process and to evaluate the performance of the semiconductor product before manufacturing.

Figure 1 depicts the trend in the annual number of fabless and integrated firms (also known as integrated device manufacturers (IDMs)) that were active in the semiconductor industry from 1984 to 2008. It presents an interesting dichotomy on the industry's vertical structure. Although the semiconductor industry has gone through a significant period of vertical disintegration driven by the entry of fabless firms, integrated incumbents have continued to persist and coexist with the fabless entrants. Only a small minority of integrated incumbents switched from vertical integration to specialization, and almost all of the integrated incumbents have continued to survive in the industry during this period[5]—despite the fact that technology progress during this period was achieved along the performance trajectory specified by Moore's law. Hence, the industry has not faced any technology discontinuities that may favor (re)integration (Afuah 2001, Jacobides and Winter 2005, Malerba et al. 2008). Note that although a number of fabless firms existed in the 1980s, they competed in small niche markets or, as a result of long development and commercialization cycles in the industry, were yet to commercialize products in the mainstream semiconductor market segments. The viability of the specialized form and its potential threat to the integrated form was not established until the mid-1990s (e.g., Strojvas 2005). For example, the first trade association representing fabless firms, the Fabless Semiconductor Association, was only incorporated in 1994, and the switch from integration to specialization by the small number of integrated firms began only in the late 1990s.

In assessing the performance difference between integrated and specialized firms, Table 1 provides a regression analysis of the effect of firm- and industry-specific factors on the firm's return on invested capital (ROIC) from 1993 to 2007.[6] There is a significant effect of firm size, firm age, industry growth, and country of origin on firm performance. However, the analysis fails to reject the null hypothesis of no significant difference in the performance between fabless and IDM firms. Strojvas (2005) conducts a similar analysis that compares the ROIC performance of the sample of integrated and fabless firms whose stocks are listed on a major U.S. stock exchange and found support for the financial viability of integrated firms from 1994 to 2003.

In summary, whereas the semiconductor industry has been subjected to the wave of disintegration that is characteristic of many established industries (e.g., Langlois 1992, Christensen 1993, Fine 1998, Baldwin and Clark 2000, Jacobides 2005), integrated firms seem to have adapted in ways that have allowed them to coexist with the specialized entrants. To identify the possible reasons for this observed coexistence of specialized and integrated firms in the semiconductor industry, I next examine the strategic response of the integrated incumbents in the face of industry's vertical disintegration.

Figure 1 **Number of Fabless (Specialized) and IDM (Integrated) Firms in the Semiconductor Industry**



Note. Data include only publicly traded firms.

Autonomous vs. Systemic Innovations

I assess whether the period of industry's transformation was associated with IDM firms shifting their innovation

Table 1 Regression Estimates for Firms' Annual ROIC from 1993 to 2007

Variable	Estimate
Fabless (vs. IDM)	0.007 (0.066)
Firm size (log(sales in US$))	0.080** (0.033)
Firm age	−0.003* (0.002)
Conglomerate	−0.133 (0.088)
Industry revenue	−0.001 (0.001)
Industry revenue growth	0.208** (0.100)
Japanese firm	0.024 (0.102)
Taiwanese firm	0.227*** (0.076)
American firm	0.078 (0.091)
Constant	−0.313 (0.227)
Observations (firm-year)	2,276
R^{2a}	0.02

Notes. ROIC is the dependent variable. OLS estimation. Robust standard errors in parentheses, clustered by firm.

[a]The high diversity of firms coupled with the cyclical nature of the semiconductor industry resulted in many outliers in the ROIC data, which contributed to the very low R^2 value. As an alternative, I winsorized the *ROIC* variable at the 1st and 99th percentiles of the distribution and reran the analysis. Whereas the R^2 value increased to 0.21, the estimate for fabless firm continued to be insignificant.

$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

efforts toward systemic innovations (Teece 1984, 1996). The analysis is carried out using annual data on IDM and fabless firms' patent grants that are filed in the 15-year period between 1993 and 2007. This window was chosen for three main reasons. First, although a number of fabless firms existed prior to 1993, the organizational form was relatively nascent during this early stage, with fewer than half of the firms applying for a patent grant in any given year (this ratio was greater than 90% for IDM firms during the same period), and of those "active" firms, about 35% applied for only a single semiconductor patent in a given year. An analysis drawing on fabless firms' patent data in this early stage of the industry's vertical specialization will likely be subjected to a strong selection bias and inferential problems associated with small numbers. Second, as observed by Hall and Ziedonis (2001), the changes in the U.S. legal environment during the 1980s increased the semiconductor firms' incentives to obtain patents for their innovations. Hence, by starting my observation at 1993, I control for this potentially confounding effect in my analysis. As a robustness check, I performed additional analysis for IDM firms using the 25-year window between 1983 and 2007 and found the observed patterns to be very similar to the main results. Third, it takes on average about two years for a patent application to be granted. Many of the patent applications that are filed in or after 2008 are unlikely to be granted by 2009, the last year for which the data for the study were collected. Note also that a lag of about one to two years is expected between the time an R&D project is initiated and the time a patent application is filed.

There are many caveats regarding the use of patents as an indicator of firms' R&D activities (e.g., Griliches 1990, Cohen et al. 2000). Most notably, the propensity and motivation for firms to patent their innovations differs across industries. By focusing on a single industry—the one in which firms are known to have a very high propensity to patent (Hall and Ziedonis 2001)—I can somewhat mitigate this concern. In addition, the use of patent counts as a proxy for firms' R&D efforts can also be problematic in certain contexts. In this study, I do not consider patent counts as an indicator of firms' innovation activities. Rather, I consider changes in the share of firms' patents that correspond to autonomous and systemic innovations. This approach is consistent with prior research that has used patent data to study firms' development of different types of technological capabilities (e.g., Argyres 1996, Patel and Pavitt 1997, Brusoni et al. 2001).

Each patent record in the Derwent database corresponds to a specific innovation by the firm and often includes multiple patent grants as a result of applications filed in different legal jurisdictions or filed as continuations of the original invention. I use the Derwent technology classification system to identify patents corresponding to semiconductor design or manufacturing. Derwent categorizes all patents in its database into 21 distinct technology sections, each of which is divided into several classes. Section U, titled Semiconductors and Electronic Circuitry, is the primary section for all semiconductor-related patents (e.g., Ziedonis 2004). Many of the patents granted to semiconductor firms are also classified into Sections T (Computing and Control), W (Communications), and L (Refractories, Ceramics, Cement, and Electro(in)Organics). Together, these four sections account for about 97% of fabless firms' patents and about 80% of IDM firms' patents.[7]

To categorize the technology classes into semiconductor design or manufacturing, I contacted four industry experts—two of whom have been associated with IDM firms, one with a fabless firm, and one from academia.[8] Each of these experts has been active in semiconductor R&D for more than 15 years. I compiled a table that included the description of the four Derwent technology sections and all of the classes within the four sections. I then circulated the table among the four experts and asked them to identify whether the description of the class refers to semiconductor design, manufacturing, or possibly both. Given that the industry is science-based and that semiconductor design and manufacturing represent distinct technical domains, the categorization provided by the experts was highly consistent. One commented that class U14 may correspond to both semiconductor design and manufacturing activities. As a robustness check, I excluded all patents that were thus classified from the analysis. The results were very similar to those reported in the paper.

Table 2 provides the list of the different Derwent classes and their categorization into either design or manufacturing based on the feedback received from the industry experts. I used this categorization to identify the extent to which firms pursue autonomous and systemic innovations. I consider a patented innovation to be autonomous if it is categorized by either design-only or manufacturing-only classes. I consider a patented innovation to be systemic if it is categorized by both design and manufacturing classes, suggesting a strong coupling between the two distinct knowledge bases (e.g., Yayavaram and Ahuja 2008).

Figure 2 depicts the trend in the average share of firms' patents that correspond to autonomous and systemic innovations. It is based on a total of 732,854 patent records assigned to fabless and IDM firms. It also illustrates several important differences in innovative behavior between fabless and IDM firms. Given that fabless firms specialize in semiconductor design, the dominant category of patented innovation for fabless firms is design-based autonomous innovation. These innovations typically represent more than 80% of the fabless firms' patents; this ratio is fairly stable over time. The small remainder tends to be shared between manufacturing-based autonomous innovations and systemic innovations. The fact that specialized design firms invest in manufacturing R&D is consistent with the view that firms' knowledge boundaries tend to be broader than their production boundaries to manage the integration of external inputs or components during technology development (Brusoni et al. 2001).

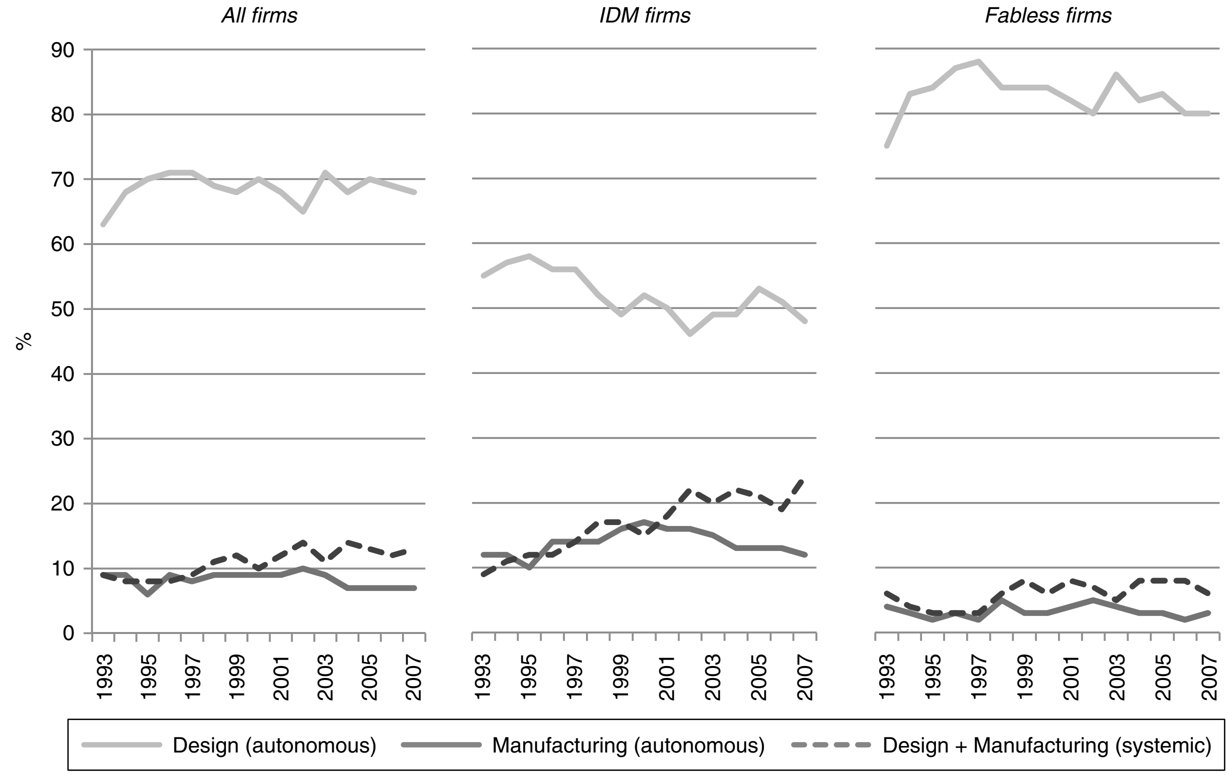
For IDM firms, the design-only innovation represents about 50% of all patents; this ratio seems, on average, to be decreasing over time. The manufacturing-only innovation represents about 15% of all patents. This ratio exhibits an increasing trend from 1993 to 2000 followed

Table 2 Classification of Derwent Classes into Design or Manufacturing

Derwent section	Derwent class	Derwent section title	Derwent class title	Class type
L	L03	Glass, ceramics, electro(In)organics	Electro(in)organics	Semiconductor manufacturing
L	L04[a]	Glass, ceramics, electro(In)organics	Semiconductors	Semiconductor manufacturing
U	U11[a]	Semiconductors and electronic circuitry	Semiconductor materials and processes	Semiconductor manufacturing
U	U12	Semiconductors and electronic circuitry	Discrete devices	Circuit design
U	U13	Semiconductors and electronic circuitry	Integrated circuits	Circuit design
U	U14[a]	Semiconductors and electronic circuitry	Memories, film, and hybrid circuits	Circuit design
U	U21[a]	Semiconductors and electronic circuitry	Logic circuits, electronic switching, and coding	Circuit design
U	U22	Semiconductors and electronic circuitry	Pulse generation and manipulation	Circuit design
U	U23	Semiconductors and electronic circuitry	Oscillation and modulation	Circuit design
U	U24	Semiconductors and electronic circuitry	Amplifiers and low-power supplies	Circuit design
U	U25	Semiconductors and electronic circuitry	Impedance networks and tuning	Circuit design
W	W01[a]	Communications	Telephone and data transmission systems	Application-specific/system design
W	W02[a]	Communications	Broadcasting, radio, and line transmission systems	Application-specific/system design
W	W03	Communications	TV and broadcast radio receivers	Application-specific/system design
W	W04[a]	Communications	Audio/video recording and systems	Application-specific/system design
W	W05	Communications	Alarm, signalling, telemetry, and telecontrol	Application-specific/system design
W	W06	Communications	Aviation, marine, and radar systems	Application-specific/system design
W	W07	Communications	Electrical military equipment and weapons	Application-specific/system design
T	T01[a]	Computing and control	Digital computers	Application-specific/system design
T	T02	Computing and control	Analogue and hybrid computers	Application-specific/system design
T	T03	Computing and control	Data recording	Application-specific/system design
T	T04	Computing and control	Computer peripheral equipment	Application-specific/system design
T	T05	Computing and control	Counting, checking, vending, ATM, and point-of-sale systems	Application-specific/system design
T	T06	Computing and control	Process and machine control	Application-specific/system design
T	T07	Computing and control	Traffic control systems	Application-specific/system design

[a]Major classes that account for at least 5% of all patents for IDM or fabless firms.

Figure 2 Average Percentage of Patents for IDM and Fabless Firms that Correspond to Autonomous and Systemic Innovations



by a slight decreasing trend from 2000 to 2007. The higher share of design patents compared with manufacturing patents can be explained in part by the fact that a given manufacturing process can be used to commercialize many different product designs.

The share of systemic innovations for IDM firms is significantly greater than that for fabless firms. On average, 17% of innovations for IDM firms are systemic, whereas this ratio is only 6% for fabless firms. This evidence is consistent with the argument that vertical integration facilitates communication as well as coordination of tasks and investments that underlie systemic innovations (Teece 1984, 1996; Monteverde 1995; Strojvas 2005; Helfat and Campo-Rembado 2010; Kapoor and Adner 2012). Industry executives from IDM firms often discuss how a tight coupling between the design and manufacturing stages facilitates the development of systemic innovations and allows their firms to create a differentiation-based advantage over fabless firms:

> It [vertical integration] allows us to develop a design and have the interaction we need with manufacturing. That synergy allows us to provide the best product for our customers. (Chekib Akrout, vice president of technology at Freescale Semiconductor, quoted in Goering 2006)

> …[I]f you're going to build a real SOC [an advanced semiconductor product that combines different types of functions on a single chip], you don't need only the basic process technology that you find in the foundries, you also need a lot of process variations that give you the differentiation you want. So your own manufacturing capability gives you a very strong competitive advantage with the ability to differentiate, and therefore add value, and therefore have a bigger margin. (Pasquale Pistorio, CEO of STMicroelectronics, quoted in Manners 2002, p. 12)

On average, the percentage of systemic innovations for IDM firms exhibits an increasing trend moving from 9% in 1993 to 24% in 2007. The percentage of systemic innovations for IDM firms has become especially high since the late 1990s. The overall trend for fabless firms seems less clear, first decreasing from 6% in 1993 to 3% in 1995, and then increasing to 8% in 1999 followed by a somewhat stable range between 8% and 6%.

I conducted unstructured interviews with senior executives in six different IDM firms to explore the organizational processes underlying this observed shift toward systemic innovations. Each of these executives held a strategic manufacturing or operations role and was employed with the firm for at least 11 years. Whereas all executives reinforced the importance of systemic innovations to their (staying) integrated strategy, the increasing emphasis on systemic innovations did not seem to be a result of a top-down strategic redesign of the organization. For example, one executive commented that his firm has been increasingly using a customized approach between design and manufacturing to differentiate and to prevent imitation. He attributed the shift toward systemic innovation to

> marketing folks telling manufacturing and design folks that they need something better to compete against the fabless-foundry model and it can't be cost.

Another executive described the shift to greater collaboration between product design and manufacturing groups that occurred informally with the emergence of specialized firms:

> At one point the technology development team will build the process, and the designers [will] just use what you got type of thing or [will] build products on the process ... now it's collaborative ... here are the features and the capabilities that we need in the process ... let's develop the process around the product road map. That's the right thing to do all along, but the existence of external foundries made that realization possible.

Hence, the organizational processes underlying the observed shift by integrated firms toward systemic innovations seems to parallel Intel's evolutionary shift from DRAMs to microprocessors shaped by managers and engineers responding to industry-level changes and leveraging their firm's superior capabilities (Burgelman 1994).

To confirm that the trend in Figure 2 with respect to systemic innovations is robust to unobserved firm-level differences, Table 3 provides results from the firm fixed effects regression analysis. The dependent variable is the firms' share of patents that correspond to systemic innovations. The independent variables include a year trend variable from 1993 to 2007 and the share of firms' patents that relate to semiconductor design and manufacturing. I report estimates using both the standard ordinary least squares (OLS) model (Models 1 and 2) and the fixed effects model (Models 3 and 4). The estimates are consistent with the trend, observed in Figure 2. The share of systemic innovations generated by IDM firms exhibits a significant positive trend, whereas the effect is quite small and weak for fabless firms. The difference in the year trend coefficient between IDM firms and fabless firms is statistically significant, with an F-statistic of 12.23 ($p < 0.01$) for the OLS models and 11.69 ($p < 0.01$) for the fixed effects models. Note also that the data from fabless firms exhibit a much poorer fit with the model ($R^2 = 0.01$) than that from the IDM firms ($R^2 = 0.14$). Models 5 and 6 are estimated by replacing the year trend variable with year dummy variables for the IDM and fabless firms, respectively. Although the estimates for IDM firms confirm the upward trend toward systemic innovations, with a significant increase in the firms' share of patents corresponding to systemic innovations since 1998 (with the exception of 2000), no such effect was found for fabless firms.

Finally, to verify that the observed trend of systemic innovation for IDM firms indeed represents a shift in their innovation activities, I performed a unit root test developed by Perron and Vogelsang (1992) on firm-level time-series data. This test allows for a structural change in the time series and provides information on the time and the direction of the change. Consistent with the organizational change literature, I use the innovational outlier model, which assumes that any structural change in the time series would be gradual as opposed to instantaneous (Perron 1990). The test was implemented using the clemio1 routine in STATA (Baum 2005). The unit root test can only be performed on firms with no gaps in the time series, leading to a sample size of 67 IDM and 43 fabless firms. The test detected a significant positive structural change at 10% or lower significance levels for 46 IDM firms and 12 fabless firms.[9] Figure 3 plots the distribution of years for which the test detected a significant positive structural change for IDM firms. Consistent with the trend reported in Figure 2, the increasing emphasis toward systemic innovation by a large majority of IDM firms seems to have started in late 1990s.

In summary, the evidence from firms' patent grants in the semiconductor industry lends support to the argument that vertical integration facilitates the development of systemic innovation (Teece 1984, 1996). More important, the analysis points to a significant shift in the innovation activities of IDM firms since the late 1990s so as to capitalize on their superiority in developing systemic innovation. Whereas fabless firms could enter and compete in the industry without incurring substantial investments in manufacturing, IDM firms having incurred these investments in the past and, having developed manufacturing capabilities, shifted their innovation efforts to systemic innovations so as to defend their competitive position against the rising tide of specialized firms.[10]

Transactional Choices

Earlier studies on industry evolution and vertical integration have shown that integrated firms, in the face of industry's disintegration, either conform to the new mode of organization by outsourcing various inputs or perish because of their inability to compete with their specialized rivals (Langlois 1992, Christensen 1993, Fine 1998, Baldwin and Clark 2000, Jacobides 2005). The case of the semiconductor industry presents a very different scenario. Only a handful of IDM firms shifted to a fabless mode between 1990 and 2008. A vast majority of firms continued to have internal manufacturing.

Instead of pursuing a more conventional make-or-buy choice, many firms leveraged the creation of markets to pursue a make-and-buy choice that entailed having their own in-house manufacturing as well as using external specialized foundry suppliers. Figure 4 plots the cumulative number of IDM firms that announced a shift in their manufacturing strategy from make to make and buy. It shows an increasing trend in the number of IDM firms using specialized foundries to carry out a proportion of their manufacturing.

Table 3 Regression Estimates for the Share of Firms' Patents Corresponding to Systemic Innovations from 1993 to 2007

	OLS		Firm fixed effects			
	IDM (Model 1)	Fabless (Model 2)	IDM (Model 3)	Fabless (Model 4)	IDM[a] (Model 5)	Fabless[a] (Model 6)
Semiconductor patent ratio	0.269***	0.057***	0.165***	0.077***	0.166***	0.076***
	(0.024)	(0.011)	(0.029)	(0.024)	(0.029)	(0.024)
Year trend	0.008***	0.002*	0.007***	0.002*		
	(0.001)	(0.001)	(0.001)	(0.001)		
1994					0.016	−0.039
					(0.024)	(0.027)
1995					0.031	−0.038
					(0.024)	(0.026)
1996					0.007	−0.045*
					(0.024)	(0.025)
1997					0.022	−0.055**
					(0.024)	(0.025)
1998					0.047**	−0.023
					(0.024)	(0.024)
1999					0.047*	−0.008
					(0.024)	(0.024)
2000					0.025	−0.025
					(0.024)	(0.024)
2001					0.058**	−0.003
					(0.024)	(0.023)
2002					0.081***	−0.010
					(0.024)	(0.023)
2003					0.069***	−0.032
					(0.024)	(0.023)
2004					0.086***	0.004
					(0.024)	(0.023)
2005					0.078***	−0.006
					(0.024)	(0.023)
2006					0.065***	0.002
					(0.024)	(0.023)
2007					0.115***	−0.028
					(0.024)	(0.023)
Constant	−0.120***	−0.008	−0.021	−0.026	−0.018	0.011
	(0.017)	(0.012)	(0.025)	(0.024)	(0.029)	(0.030)
Number of observations	1,576	1,840	1,576	1,840	1,576	1,840
Number of firms	158	236	158	236	158	236
R^2	0.14	0.01	0.14	0.01	0.15	0.02

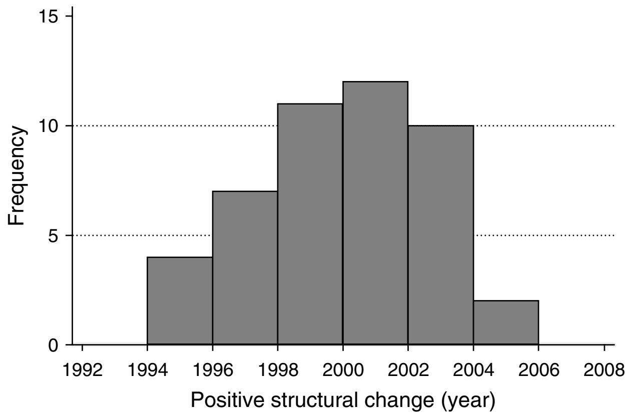
Notes. Standard errors are in parentheses (clustered by firm for OLS models). The data include publicly listed and private IDM firms that are recorded in SEMI's World Fab Watch database.
[a]Year 1993 is the omitted year dummy.
$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

This plural mode of internal and external sourcing allowed IDM firms flexibility with respect to their R&D and capacity investments especially during periods of high demand uncertainty (e.g., Harrigan 1985, Parmigiani 2007).[11] For example, STMicroelectronics, one of the largest European-based semiconductor firms, discussed the benefit of this strategic shift in its 2003 annual report:

> We have also developed relationships with outside contractors for foundry and back-end services. We view these relationships as giving us the flexibility when required by market demand to outsource up to a maximum of 20% of each of our front-end and back-end production requirements, enabling us to manage the supply chain to our customers without a commensurate increase in capital spending. (STMicroelectronics 2003, p. 22)

In addition to gaining flexibility, the make-and-buy choice also enabled IDM firms to access external suppliers for certain types of manufacturing processes for which specialized foundries may be more efficient and to focus their internal efforts on manufacturing processes for which integrated firms may be more efficient.

Figure 3 Distribution of Years for Which the Unit Root Test Detected a Significant Positive Structural Change



Note. This is for the share of IDM firms' patents corresponding to systemic innovations between 1993 and 2007.

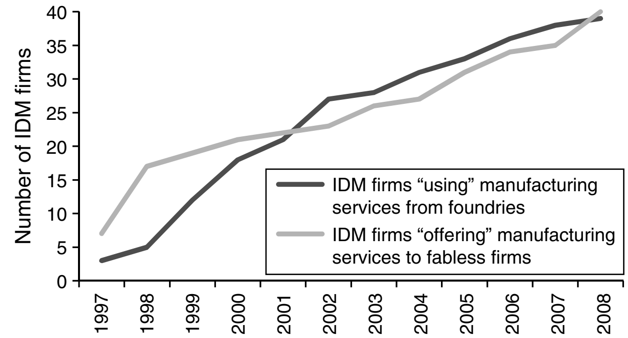
For example, Texas Instruments (TI), one of the largest U.S.-based semiconductor firms, leveraged its and its suppliers' differentiated capabilities by using a combination of external and internal manufacturing for digital processes while pursuing an internal-only route for analog processes. TI discussed the benefit of this strategy in its 2007 annual report:

> TI benefited from its hybrid manufacturing model, with the company employing a combination of internal and third-party foundry manufacturing for advanced digital processes. This hybrid approach provided the company with more flexibility in its operations to adapt to changing market conditions yet focus its internal efforts more intently on analog. TI continued to enhance its analog capabilities, significantly increasing the number of researchers involved in analog process development while also expanding analog manufacturing capacity.
> (Texas Instruments 2007, p. 3)

An alternative approach to evaluating the transactions between integrated firms and specialized foundries is presented in Figure 4, which provides data from the "other" side of the transaction. It plots the percentage sales to IDM firms from 1998 to 2008 for the two largest specialized foundries—Taiwan Semiconductor Manufacturing Corporation (TSMC) and United Microelectronics Corporation (UMC). TSMC and UMC together accounted for more than 60% of the worldwide foundry market share during this period. Whereas the two foundries have exhibited dramatic growth, IDM firms have constituted an important market segment for these foundries, and sales to IDM firms have represented, on average, about 30% of their total annual sales. Hence, the data plotted in Figure 5 are consistent with the make-and-buy industry trend observed in Figure 4.

Besides the opportunity of benefitting from the make-and-buy mode, the specialization of industry also presented integrated firms with an opportunity to participate

Figure 4 Number of IDM Firms Using and Offering Manufacturing Services



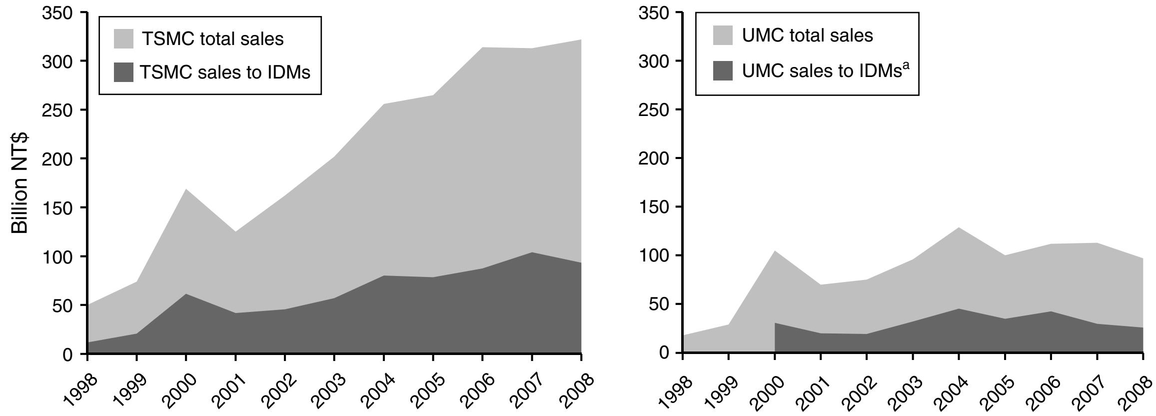
in intermediate markets by offering their manufacturing services to fabless firms in addition to their own internal use. Figure 4 shows the trend in the number of IDM firms offering their manufacturing services to fabless firms. There has been a rapid rise in the number of IDM firms offering such services. In 1997, only 7 of the IDMs participated in the intermediate market for manufacturing, whereas in 2008, this number grew to 39. This strategy had a direct benefit of providing integrated firms with additional demand for their manufacturing capabilities and helping economize on high fixed costs of R&D and production. For example, IBM was one of the earliest of the integrated incumbents to embrace this strategy and highlighted it as a key part of its transformation during the 1990s:

> There was a time when all our component technologies, such as semiconductors and hard disk drives, went inside our own products. And only there. That was then, this is now. In order to support our massive investments in R&D, we needed additional revenue streams, so we began doing something previously unthinkable—selling our technology products to other high-tech companies. Fortunately, our technology was so good that we sold a lot of it—multibillion dollars' worth.... In 2001, IBM was one of only two top-30 chip makers that grew revenue.
> (IBM 2001, p. 29)

Besides creating greater demand for incumbents' manufacturing assets and capabilities, this strategy also helped reduce the dominance of specialized foundries by increasing competition in upstream markets. The benefit of having a greater number of manufacturing suppliers was often a key part of the sales pitch by executives at IDM firms offering their manufacturing services to fabless firms (Morrison 1998). Finally, by selling their manufacturing capacity to external customers, the corporate office mitigated the organizational inefficiencies associated with low-powered incentives of the hierarchies (Williamson 1985) and helped ensure that the upstream manufacturing unit remained competitive.

In summary, the evidence regarding the transactional choices pursued by integrated incumbents shows how the emergence of specialized firms presented integrated

Figure 5 Sales Trend for TSMC and UMC, the Two Largest Foundries (Specialized Manufacturing Firms) in the Semiconductor Industry



[a]UMC did not report its sales to IDM firms for the years 1998 and 1999.

incumbents with new corporate alternatives for creating value. These value-creating opportunities were enabled by the presence of specialized firms. Participation in intermediate markets as manufacturing suppliers to fabless firms and the shift to the make-and-buy mode of manufacturing allowed the integrated firms to leverage markets and gain supply-side efficiencies while retaining their ability to develop and commercialize systemic innovations.

Alternative Explanations

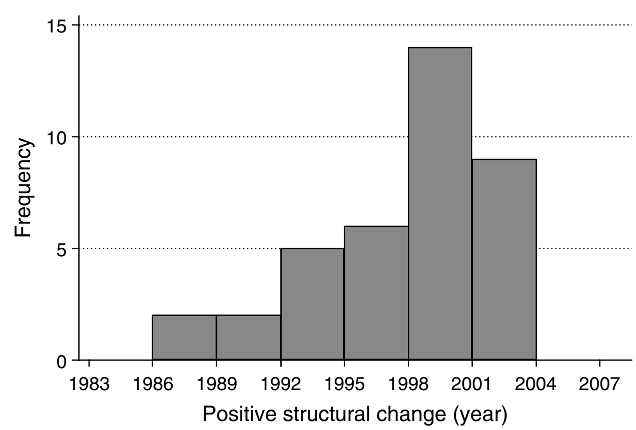
The arguments and the evidence presented in the study suggest that the persistence of integrated firms in the face of the semiconductor industry's vertical disintegration is facilitated by the strategic reconfigurations pursued by incumbents that entail shifting their innovation activities toward systemic innovations and transacting with specialized firms in upstream and intermediate markets while staying integrated. However, there may be other possible explanations for the observed pattern of systemic innovations and why integrated firms may continue to exist in the semiconductor industry.

First, it is possible that integrated firms' emphasis toward systemic innovations may have been initiated earlier and somewhat independent of the threat from specialized firms. To address this possibility, I performed the structural change analysis on IDM firms' proportion of systemic innovations from 1983 to 2007. A significant positive structural change in the 1980s or even the early 1990s would be consistent with this alternative explanation. Figure 6 plots the distribution of years for which the test detected a significant positive structural change for IDM firms. As in the main analysis, the increasing emphasis by a large majority of IDM firms toward systemic innovation seems to have started in the late 1990s.

Second, the observed shift in the emphasis on systemic innovations could be an artifact of the relative shift in the integrated firms' reliance on patents (instead of secrecy) for appropriating value from systemic innovations (Cohen et al. 2000). Although this is a plausible alternative explanation, there is strong evidence that integrated firms in the semiconductor industry since the late 1980s have been aggressively patenting their innovations for defense reasons such as to protect themselves from patent infringement suits and to use them as bargaining chips during negotiations with other patent owners (Hall and Ziedonis 2001). Hence, any shift in the use of secrecy as an appropriability mechanism for systemic innovations is unlikely to be the main driver of the observed increase in the proportion of systemic innovations for IDM firms.

Third, it is possible that having incurred substantial investments in manufacturing in the past, incumbents may rationally choose to stay integrated so as to leverage their sunk costs and avoid additional costs that may be associated with disintegration (Porter 1980). I cannot rule out this possibility, but the fact that the semiconductor industry is characterized by a high degree of

Figure 6 Distribution of Years for Which the Unit Root Test Detected a Significant Positive Structural Change



Note. This is for the share of IDM firms' patents corresponding to systemic innovations between 1983 and 2007.

technological obsolescence, and that firms in the industry continuously invest in new manufacturing plants and equipment to improve product performance and gain production efficiencies, suggests that this explanation is unlikely to be the main driver of coexistence.

Finally, it is also possible that integrated firms may be more diversified than specialized firms and, hence, derive greater economies of scope from their manufacturing capabilities. As argued by Teece (1982), economies of scope on its own is not sufficient to explain integration. It must be coupled with coordination efficiencies between interdependent activities to justify integration. Such coordination efficiencies within integrated firms are likely to exist with respect to systemic innovations (Teece 1996).

Discussion and Conclusion

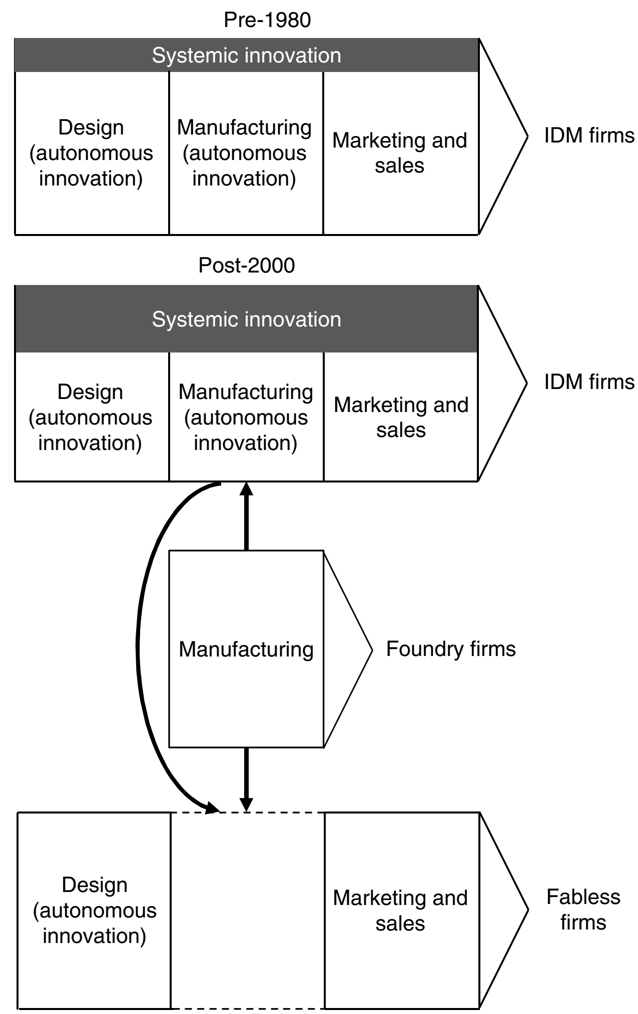
The literature on industry evolution and vertical integration has generated valuable insights regarding why industries shift from a vertically integrated to a specialized structure over their life cycle (Stigler 1951, Baldwin and Clark 2000, Lamoreaux et al. 2003, Jacobides 2005). Many industries, however, are characterized by a continued persistence of integrated firms despite a trend toward vertical disintegration (Christensen et al. 2002, Argyres and Bigelow 2010, Helfat and Campo-Rembado 2010, Kapoor and Adner 2012). In this study, I explore the underlying drivers of such persistence by considering how integrated incumbents may adapt in the face of the industry's vertical specialization and continue to coexist with the specialized firms.

I draw on transaction cost economics, capabilities-based, and modularity theories to identify a reconfiguration menu that entails different types of innovations and transactional choices that integrated firms may pursue as the industry is populated by specialized firms. I differentiate systemic innovations that require extensive coordination and communication across different stages of production from autonomous innovations that can be commercialized without significant adjustments to other stages of production (e.g., Teece 1984, 1996; Langlois and Robertson 1995; Hoetker 2006). I consider the firm's set of transactional choices to not only include the traditional make-or-buy choice but also include choices that may allow firms to generate supply-side efficiencies by leveraging markets while staying integrated (Harrigan 1984, Jacobides and Billinger 2006, Parmigiani 2007, Luo et al. 2012).

The analysis is conducted in the context of the global semiconductor industry. Since the 1980s, the industry has transitioned from an integrated structure to a more specialized structure. The change in the industry structure was driven by the entry of specialized fabless firms who design and sell semiconductor products but rely on external suppliers for manufacturing. However, for over two decades, a vast majority of integrated incumbents have continued to persist and coexist with the specialized firms. I draw on a unique array of archival data including information on firms' innovation activities and transactional choices to uncover the possible drivers of coexistence. Evidence from the semiconductor industry supports the argument that the persistence of integrated firms in the face of industry's vertical disintegration is associated with integrated firms increasing their emphasis on systemic innovations and transacting with specialized firms in upstream and intermediate markets.

Figure 7 uses the value chain approach to illustrate the study's findings. It shows how the semiconductor industry evolved from being dominated by integrated IDM firms performing design, manufacturing, and marketing activities to an ecosystem of integrated and specialized firms transacting with each other through markets for manufacturing. The figure also shows the difference in innovation activities between IDM and fabless firms with respect to autonomous and systemic innovations, as well as the observed shift by IDM firms toward systemic innovations.

Figure 7 Evolution of the Semiconductor Industry



These findings help generate a simple framework to explain the pattern of industry's vertical disintegration. It suggests that as an industry transitions from an integrated to a specialized structure, there is a shift in the distribution of capabilities among industry participants. This shift presents new value-creating opportunities for integrated firms that include leveraging their relative superiority in developing systemic innovations and leveraging the availability of markets for upstream and downstream activities to pursue a broader menu of transactional choices. The extent to which firms' costs of staying integrated will be offset by supply-side efficiency gains from transacting with specialized firms, and the demand-side premium from systemic innovations will determine the pattern of industry's vertical disintegration and the nature of coexistence between integrated and specialized firms.

The framework supplements existing accounts of industry evolution and vertical integration that have predominantly focused on explaining the emergence and the eventual dominance of the specialized organizational form (e.g., Langlois 1992, Christensen 1993, Fine 1998, Baldwin and Clark 2000, Jacobides 2005). In so doing, the extant literature has tended to either implicitly or explicitly assume that the rise of the specialized form corresponds to the demise of the integrated form. By considering the relative advantage that integrated firms enjoy in competing through systemic innovations and by allowing for transactions between integrated and specialized firms in both upstream and intermediate markets, the framework developed in the study blends evolutionary approaches with strategic ones to give a more prominent role to how integrated firms can adapt in the face of industry's vertical disintegration and coexist with the specialized firms.

The evidence from the semiconductor industry also contrasts studies of transactional alignment during a period of significant industry change (Nickerson and Silverman 2003, Argyres and Bigelow 2007). These examinations have argued for firms to realign their governance mode, but integrated firms in the semiconductor industry seem to have taken an alternative route through learning and more efficiently managing their preexisting governance mode (Argyres 2011).

The study has a number of limitations, and I hope that future research will address these shortcomings. First, the study is carried out in the context of a single industry. The generalizability of the findings and the validity of the suggested framework would need to be established through exploration in other industries. Second, although the use of patent data enabled the examination of firms' innovation activities in the semiconductor industry, the measure is not applicable in all industries. Future work could explore other measures to assess differences in the type of innovations pursued by integrated and specialized firms. Third, although I present some preliminary evidence on the performance of integrated and specialized firms, much more needs to be done to understand the sources of performance differences both between and within the two forms of organization in the context of industry's vertical disintegration. For example, IDM firms' participation in intermediate and upstream markets would require establishing new marketing and sales capabilities to support new types of customers, as well as developing procurement capabilities to manage relationships with external suppliers. Perhaps more important, it would require that corporate executives modify existing organizational designs and incentive structures for the internal business units to support each other while maintaining relationships with external suppliers and customers. Hence, the relative success of integrated incumbents would be bound by the organizational challenges and inertia that they may face in reconfiguring their activities and exploiting opportunities in upstream and intermediate product markets. Fourth, given the different types of transactional reconfigurations that I study, an obvious issue to consider is the nature of variance among firms. The extent to which integrated firms pursue transactions in upstream and intermediate markets is likely to be a function of transaction costs and the distribution of capabilities among specialized and integrated firms. For example, whether and to what extent integrated firms participate in intermediate markets will depend on the specialized investments required to support customers in such markets as well as the appropriability hazards that firms may be subjected to by sharing their intellectual property with firms who may be current or potential competitors (Baldwin and Henkel 2012, Luo et al. 2012). Similarly, the extent to which integrated firms use external manufacturing suppliers will likely be shaped by the firms' and suppliers' scope economies, capabilities, and technological uncertainty (e.g., Parmigiani 2007).

Despite these and other limitations, I hope that the study has provided an important step forward in our understanding of the interaction between vertical integration and industry evolution. It departs from the stylized model of industry evolution characterized by the shift from integration to specialization with an explicit consideration of how integrated incumbents may reconfigure their activities in the face of the industry's vertical disintegration so as to coexist with the specialized firms. By providing evidence that the persistence of integrated incumbents is associated with incumbents increasing their emphasis on systemic innovations and transacting with specialized firms in both upstream and intermediate markets, the study argues against the somewhat popular imagery of the creative destruction of the integrated form by the specialized form. In doing so, it contributes to the broader agenda of explaining how industry-level evolutionary processes interact with firm-level adaptation to shape industry structure.

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Endnotes

[1]Note that although these studies have explicitly considered firms' preentry capabilities and the relative effectiveness of integrated and specialized firms with respect to different competitive positions or types of innovation, they have not explicitly considered or shown the different ways in which integrated firms can adapt as the industry shifts from an integrated to a specialized structure.

[2]Brusoni et al. (2001) offer another important perspective on industry's vertical specialization and the firms' menu of organizational choices by distinguishing "division of labor" from "division of knowledge." The authors argue and show that despite the narrowing of firms' production boundaries observed in a number of industries, specialized firms that are involved in multicomponent, multitechnology products may still need to invest in knowledge of outsourced components in order to manage technological interdependencies and uneven rates of progress in components. Hence, beyond the transactional choices considered in this study, the menu of organizational choices can be broadened to include choices with respect to knowledge boundaries.

[3]In this study, I draw on the firm boundaries literature to differentiate between autonomous and systemic innovations. Note that whereas scholars drawing on transaction cost economics have tended to use this typology (e.g., Teece 1984, 1996; Langlois 1992; Langlois and Robertson 1995; Hoetker 2006), other scholars drawing on modularity theory have referred to similar innovations as modular or integral design/architecture (e.g., Ulrich 1995, Baldwin and Clark 2000, Colfer and Baldwin 2010, Fixson and Park 2008). Note also that this typology emphasizes somewhat deliberate choices by firms compared with the typology developed by Henderson and Clark (1990), which emphasizes somewhat exogenous changes in technology.

[4]There are many privately held fabless semiconductor startups, but they represent a very small fraction (less than 1%) of the total industry revenue. Because of the capital-intensive nature of the semiconductor industry, firms, once they achieve a certain scale, tend to get publicly listed.

[5]The firms that switched from integration to specialization included Ramtron in 1998; Zarlink Semiconductor and Xicor in 2001; Semtech in 2002; Applied Micro Circuits, California Micro Devices, and Conexant Systems in 2003; Zilog in 2004; Avago Technologies in 2005; and the LSI Corporation in 2006.

[6]ROIC has been widely used as a measure of firm performance both by managers and by investors (Porter 2008). It is particularly attractive in the case of the semiconductor industry because it not only accounts for the capital required to generate returns but also accounts for the differences in the capital structure and tax structures across firms and countries. I also experimented with the return on sales measure and found no significant difference in the performance between IDM and fabless firms. An alternative measure of performance that I would have preferred to use is firm survival. However, there are some theoretical and empirical issues with the use of firm survival to compare the performance difference between IDM and fabless firms. First, exit barriers for fabless firms are significantly lower than that for IDM firms, making the interpretation of findings from firm survival models problematic. Second, the difference in the exit rates between fabless and IDM firms could in part be due to competition within these organizational forms rather than between organizational forms, especially as the industry witnessed a high rate of entry by fabless firms in early 1990s. Finally, there were very few exit events by IDM firms during the period of the study and most of those were driven by mergers or acquisitions.

[7]The percentage of semiconductor related patents identified for IDM firms was lower than that for fabless firms as a number of IDM firms such as Hitachi and Toshiba are diversified conglomerates and, hence, are active in many different industries and technologies.

[8]These experts were identified based on my ongoing interactions with them as part of a multiyear field study of the semiconductor industry. They had expressed strong interest in the research topic and were also familiar with the different patent classification systems. One of the experts was an inventor at IBM where the Derwent patent database was originally developed.

[9]The estimation for structural change was insignificant for 16 IDM and 28 fabless firms and was negative for 5 IDM and 3 fabless firms.

[10]To assess the relative importance of systemic innovations over autonomous innovations, I performed a supplementary analysis using patent forward citation information. Unlike U.S. Patent and Trademark Office patent data made available through the NBER patent database that readily includes citation information as a separate field, the Derwent patent database requires a Web-enabled citation search for each patent record. This makes the retrieval of patent citation information from Derwent very resource intensive. Hence, instead of collecting patent citation data for each patent record, I used a random sampling approach. I created a random sample of 2,400 patent records that included 400 patent records for each innovation type (systemic, design, and manufacturing) for IDM and fabless firms, respectively. Although I found strong evidence for systemic innovations being more important than manufacturing innovations as measured through a count of forward citations, the evidence for systemic innovations being more important than design innovations was quite weak. Moreover, consistent with my arguments and the qualitative evidence, I found that systemic innovations are more important to the IDM firms' competitive position as measured through a count of self-citations than design or manufacturing innovations (e.g., Hall et al. 2005).

[11]In some cases, the make-and-buy choice pursued by IDM firms also accompanied licensing of certain types of process technologies from IDMs to foundries.

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