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THE IMPACT OF ACQUISITIONS ON THE PRODUCTIVITY OF INVENTORS AT SEMICONDUCTOR FIRMS: A SYNTHESIS OF KNOWLEDGE-BASED AND INCENTIVE-BASED PERSPECTIVES

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We show how knowledge-based and incentive-based perspectives complement each other to explain the effects of acquisitions on the productivity of inventors from acquired firms. Incentive-based theories account for their lower productivity relative to that of inventors at nonacquired firms, and both perspectives jointly explain why their productivity converges with that of inventors from acquiring firms. Higher productivity is achieved when there is greater overlap in routines and moderate overlap in skills, and when the acquired firm is large relative to its acquirer. This study clarifies the subtle manner in which incentives and the knowledge-based view are intertwined.

Firms competing in R&D-intensive industries are increasingly acquiring other firms as a means of obtaining new technological competencies (Bower, 2001; Chaudhuri & Tabrizi, 1999). Scholars have uncovered important mechanisms by which technology-based acquisitions can increase a firm's competitive advantage (Ahuja & Katila, 2001; Graebner, 2004; Nicholls-Nixon & Woo, 2003; Puranam, Singh, & Zollo, 2006). Among the most important resources involved in such acquisitions are the knowledge workers from the target firm (Ernst & Vitt, 2000; Graebner, 2004; Ranft & Lord, 2000, 2002). However, empirical examination of acquired employees has been limited to qualitative studies and small-sample surveys, mainly because it is difficult to observe such resources after they are absorbed into an acquiring firm.

In this article, we show how the knowledge-based and incentive-based perspectives complement one another to explain the effects of acquisition on the productivity of inventors from acquired firms. There have been extensive debates among management scholars regarding how knowledge resources and firm boundaries affect competitive advantage (Foss, 1996a, 1996b; Grandori & Kogut, 2002; Kogut & Zander, 1992, 1996; Williamson, 1999). The knowledge-based approach, according to which a firm is a repository of socially embedded knowledge, emphasizes superior coordination and learning by employees inside the firm (Kogut & Zander, 1992; Nelson & Winter, 1982). In contrast, the incentive-based approach, according to which a firm is a bundle of contracts, emphasizes the efficient alignment of employee incentives under different structural conditions (Hart & Moore, 1990; Holmstrom, 1979). The tension between the two perspectives is evident in the following:

> Our view differs radically from that of the firm as a bundle of contracts that serves to allocate efficiently property rights. In contrast to the contract approach to understanding organizations, the assumption of the selfish motives of individuals resulting in shirking or dishonesty is not a necessary premise in our argument. Rather, we suggest that organizations are social communities in which individual and social expertise is transformed into economically useful products and services by the application of a set of higher-order organizing principles. (Kogut & Zander, 1996: 384)

There is growing recognition that researchers taking the knowledge-based view can benefit from

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paying greater attention to incentives (Coff, 2003; Foss, 1996a; Ziedonis, 2004). This may be especially true when they are examining innovation-related activities, where effort and learning have a high degree of complementarity (Foss, 1996a). In keeping with the above, Dosi, Levinthal, and Marengo (2003) created a formal model that links a firm's problem-solving routines with incentives to explain performance outcomes. They observed that the link between knowledge and incentives was strong in the early research that formed the foundations of the knowledge-based perspective (Cyert & March, 1963; March & Simon, 1958; Nelson & Winter, 1982) but that these links were lost in subsequent work. They concluded that more research integrating both perspectives is needed.

Technology acquisitions are a suitable context for examining the integration of knowledge-based and incentive-based perspectives. Acquisitions involve an aggregation of two distinct knowledge bases. Moreover, they involve a realignment of incentives for acquired R&D employees (Williamson, 1985: 161). We chose to analyze the U.S. semiconductor industry because acquisitions have become a major mechanism for assimilating and integrating external knowledge in this industry (Griffin, 1989; Vanhaverbeke, Duysters, & Noorderhaven, 2002). We used patent data to identify inventors from acquired firms and to measure their productivity before and after acquisition relative to the productivity of two separate control groups.

Our results show the specific manner in which knowledge-based and incentive-based effects are intertwined in the context of acquisitions. We find support for both knowledge- and incentive-based predictions of lower productivity among acquired inventors immediately following an acquisition, relative to a control group of nonacquired inventors. However, the two perspectives differ subtly with regards to predicting how inventor postacquisition productivity changes over time:[1] the incentive-based approach leads us to hypothesize a persistent decline in postacquisition inventor performance relative to the performance of inventors in *nonacquired* firms, but the two perspectives jointly suggest that the productivity of acquired inventors will converge to the level of inventors from the *acquiring* firms. In addition, the incentive-based approach also accounts for a negative relationship between relative firm size and performance. The knowledge-based perspective accounts for a positive impact of routines overlap and an inverted U-shaped relationship between skills overlap and performance.

We hope these findings will encourage scholars to expand the boundaries of knowledge-based research and examine the conditions that enable a firm to appropriate value from knowledge resources. For example, the difficulties of transferring knowledge within a firm may result not only from a lack of well-defined routines (Winter & Szulanski, 2001) but also from the misalignment of incentives between a source and a recipient. Similarly, the effectiveness of interfirm alliances for sharing knowledge may depend on how the incentives of the alliance partners are aligned (Khanna, Gulati & Nohria, 1998). Our results may also persuade scholars using an incentive-based approach to more deeply understand how the nature and social embeddedness of knowledge affect a firm's governance structures and alignment of incentives (Conner & Prahalad, 1996: 492).

Our findings also contribute to the literature on technology acquisitions and firm performance. Most prior related research has examined aggregate firm-level outcomes following an acquisition; we instead shed light on the performance of a key acquired resource. We further suggest that although retaining talent is important, further research is needed to understand the conditions under which that talent remains productive. Moreover, by using individual-level analysis, we were able to obtain an "inside the box" view of earlier firm-level studies (Ahuja & Katila, 2001; Hitt, Hoskisson, Ireland, & Harrison, 1991; Nicholls-Nixon & Woo, 2003) while showing that several factors—skills overlap, routines overlap, relative firm size, and integration—shaped the individual-level results for inventors.

THEORY AND HYPOTHESES

The Importance of Inventors from Acquired Firms

Acquisitions are an important means by which firms can assimilate technological and organizational capabilities possessed by acquired firms (Ahuja & Katila 2001; Chaudhuri & Tabrizi, 1999; Puranam, Singh, & Zollo, 2006). Acquisitions allow a firm to obtain knowledge that is of high strategic importance but low familiarity (Leonard-Barton, 1995: 144) and to reconfigure its business capabilities (Karim & Mitchell, 2000). Acquisitions are therefore important in R&D-intensive industries, which are characterized by high uncertainty and a need to constantly develop new capabilities. In recent years, acquiring firms for the knowledge they possess has increased in importance (Bower, 2001),

[1] We thank an anonymous reviewer for suggesting that we explore temporal changes in inventor productivity.

and the number of acquisitions in technology-intensive industries such as pharmaceuticals, electronics, telecommunications, and biotechnology has risen dramatically (Sikora, 2000).

Of particular value to an acquiring firm are the experience and the skills of technical personnel from the acquired firm (Kozin & Young, 1994). According to Mayer and Kenney (2004), the retention of employees from acquisitions is a key consideration for successful firms such as Cisco. Puranam et al. (2003) quoted a manager from Cisco: "Usually we purchase a specific piece of technology or a product. But that is only half the story, we also want the team which will generate innovation in the future." When human capital is the most important asset being acquired, surely an important consideration is that the acquired inventors remain productive after the acquisition. Prior research has examined various postacquisition employee outcomes, including psychological issues (e.g., Marks & Mirvis, 1986), career concerns (e.g., Walsh, 1989), and cultural fit (e.g., Buono, Bowditch, & Lewis, 1985). These perspectives help us to understand the mechanisms that determine employee reactions following an acquisition, as well as the reasons for the limited success of many acquisitions (Haspeslagh & Jemison, 1991). More recently, scholars have developed and tested predictions using the knowledge-based view (e.g., Ranft & Lord, 2000, 2002), which is an appropriate theoretical lens given the importance in acquisitions of knowledge embodied in people, practices, and intellectual property. The foundations of this perspective rest on conceptualizing organizational skills and routines as the building blocks for firm capabilities and behavior (Cyert & March, 1963; Nelson & Winter, 1982). The knowledge-based view identifies firms as repositories of knowledge and posits that the efficiency of firms over markets is achieved through superior coordination and learning that is facilitated by social context (Kogut & Zander, 1996). The context-specific nature of knowledge makes it difficult to imitate and replicate (Szulanski, 1996), thereby making it difficult for firms to integrate new knowledge (Grant, 1996). The knowledge-based literature offers valuable insights into how firms might overcome these obstacles, by addressing the mechanisms for integrating knowledge from acquired firms and retaining talented individuals (Graebner, 2004; Ranft & Lord, 2000, 2002).

Although the knowledge-based perspective has succeeded in offering valuable insights into firms' integration of external knowledge, greater attention is needed to understand how such knowledge resources interact with economic incentives (Coff, 2003; Dosi, Levinthal, & Marengo, 2003; Foss, 1996a; Kim & Mahoney, 2002; Ziedonis, 2004). A focus on incentives can help to clarify whether a firm's resources will be productively used following an acquisition (Williamson, 1985: 161). In the remainder of this section, we combine insights from the knowledge-based and incentive-based perspectives to derive our hypotheses. Each perspective on its own provides a partial explanation, but taken together they provide a more complete view of the determinants of inventor productivity following an acquisition.

Postacquisition Productivity of Inventors

Despite the importance of acquisitions as a source of new knowledge, many technology-oriented acquisitions suffer from disappointing performance (Chaudhuri & Tabrizi, 1999). A growing body of research has started to examine the factors that influence a firm's ability to appropriate the benefit from acquired knowledge resources (Ahuja & Katila, 2001; Graebner, 2004; Puranam, Singh, & Zollo, 2006; Ranft & Lord, 2000, 2002). Many of these studies are at the organizational level of analysis; less attention has been given to the individual level. Ernst and Vitt (2000) showed that acquisitions resulted in key inventors becoming less productive or leaving the acquired firms. However, this study covered only 61 inventors from Germany, and only "key" inventors (i.e., those with high patent activity and patent quality) in the acquired firms were included.[2] The lack of scholarly studies on this issue is likely a consequence of the empirical difficulty of tracing inventors and other knowledge-based resources acquired after they become part of the combined entity. Nonetheless, the issue remains important for management research (Graebner, 2004; Puranam et al., 2006).

We propose that incentive-based and knowledge-based approaches complement one another in explaining the postacquisition performance of inventors. Research on incentives dates back to Adam Smith (1776), who studied the incentives of workers in factories. Incentives research has shown that it is important to balance intrinsic against extrinsic rewards (Barnard, 1938: 142) and to ensure that

[2] Ernst and Vitt did not account for interindustry variation or control for inventor life cycle effects (Levin & Stephan, 1991) and labor mobility (Almeida & Kogut, 1999). Moreover, changes in incentives after an acquisition may be less severe in Germany owing to institutional factors such as standardized wages in certain industries, employee collective bargaining through unionization, low wage differentiation within firms, and high job security (Siebert, 1997).

incentives are adequate to promote cooperation and coordination (Barney & Ouchi, 1986; Thompson, 1967). Information asymmetry, or the "principal-agent" problem (Laffont & Martimort, 2002) makes it difficult to set up an effective incentive system. When one party (the principal) delegates activities to another (the agent), private information held by the agent restricts incentive effectiveness, either because the actions of the agent are difficult for the principal to monitor—which leads to moral hazard, or the temptation for the agent to behave opportunistically—or because of adverse selection, whereby the agent's hidden information makes it hard for the principal to select better-performing agents over weaker ones. The solution to agency problems involves a classic trade-off between "rent extraction" and efficiency: to motivate an agent to increase productivity, a principal must be willing to extract less rent and share more of the profits with the agent (Milgrom & Roberts, 1992).

In the case of technology acquisitions, agency problems are especially salient because it is difficult to monitor the activities of inventors and to assess the quality of knowledge produced. The adverse selection problem is similar to that in Akerlof's (1970) analysis of used car markets, in which a buyer is likely to encounter defects in a car that are difficult to observe prior to purchasing it. In a technology acquisition, information asymmetry is high; the acquiring firm is seeking to purchase intangible assets, including the target firm's intellectual property and technical skills. This asset intangibility increases the likelihood of adverse selection. Managers at a firm about to be acquired may inaccurately report their firm's R&D capabilities so as to obtain a favorable valuation. For example, they may know of key inventors who are unhappy with the work environment and about to disengage from critical projects; or the firm may possess patents that are attractive to an outsider but that, the managers know, are costly to transform into an actual product. The buyer, unaware of such hidden information, risks ending up with inventors or intellectual property that are less productive than expected.

Moral hazard is another source of concern for acquiring firms. An inventor is an agent who produces a highly intangible R&D-intensive product with uncertain commercial value. The inventor's activities are difficult to monitor, and failure does not provide a reliable negative signal. An inventor who fails could indeed be shirking work, or he or she could instead be researching risky and creative ideas (Sutton, 2001). According to Holmstrom (1989), moral hazard is more severe in large innovative firms than in small ones because of the need in large firms to manage and monitor multiple tasks of varying degrees of complexity. When one firm acquires another firm for its knowledge assets, the larger size of the resulting entity increases agency problems. These problems are further compounded because an acquisition involves not just a greater degree of multitasking, but also often the replacement of one principal with another. The new principal is at a disadvantage in measuring and monitoring the performance of newly acquired employees.

Apart from moral hazard and adverse selection is a third type of incentive problem: nonverifiability, or the inability of an agreement between a principal and an agent to be validated by a third party (Laffont & Martimont, 2002: 3). Nonverifiability makes it difficult for the principal and agent to write a sustainable contract that optimizes their level of effort (Hart, 1995). Under these conditions, it is important to consider transaction costs (Williamson, 1985) and property rights (Hart & Moore, 1990). Transaction cost economics, although relevant, is not central to this paper because it focuses on appropriate governance structures rather than inventor-level incentives. Property rights, however, are important because the acquisition of one firm by another involves a change in ownership of the property (both tangible and intangible) of the acquired firm. Aghion and Tirole (1994) used property rights to compare an independent research-oriented firm with the research division of another firm. They showed that the independent firm had a higher incentive to produce innovations than the research division,[3] because the research division had less control over its intellectual property and other knowledge assets and therefore received a smaller share of the value it created than the independent firm. Applying this result to acquisitions, inventors at acquired firms would have lower incentives after their firms become research divisions within the acquiring firms.

From a knowledge-based view, acquisitions disrupt the routines of the participating firms (Ranft & Lord, 2002). Both task-outcome ambiguity among employees (Buono & Bowditch, 1989) and strategic reconfigurations (Karim & Mitchell, 2000) may cause disruption. Compared to inventors from non-acquired firms, who do not face such disruptions, inventors at acquired firms likely lose productivity. Hence, both the incentive- and the knowledge-based views predict a decline in the productivity of acquired inventors following an acquisition:

[3] Although their paper is nominally about an independent research unit, their mathematical model is equally applicable when the "research unit" is an individual inventor.

Hypothesis 1. Compared to inventors from a similar but nonacquired *firm, the inventors from an acquired firm have lower innovation productivity immediately following the acquisition.*

The change in structure from being an independent firm to becoming part of the acquirer firm is permanent. Hence, the incentives of inventors from acquired firms will remain lower than the incentives of inventors from nonacquired firms. We therefore expect the gap in productivity to persist over time:

Hypothesis 2a. Compared to inventors from a similar but nonacquired *firm, the inventors from an acquired firm have persistently lower innovation productivity following the acquisition.*

Although both the target and the acquiring firm face disruptions immediately following an acquisition, the changes primarily affect the resources, routines, and activities of the acquired rather than the acquiring firm (e.g., Capron, 1999; Schweiger & Walsh, 1990). Hence, we expect a greater level of disruption among inventors from acquired firms than among those from acquiring firms. However, these disruptions are likely to exist only in the short term, until the transition to a new organizational form is completed (Amburgey, Kelly, & Barnett, 1993). Thereafter, the innovation outcomes of acquired and acquiring inventors would be shaped by common coordinating mechanisms, knowledge-sharing routines, and complementarities (Kogut & Zander, 1992, 1996). The transition period following an acquisition would also be accompanied by processes of socialization and mutual learning between new and existing employees (Feldman, 1981; March, 1991). Such processes result in an improvement in the performance of the newcomers, and their performance is stabilized once they adapt to the demands of the new organization (Chen, 2005; Murphy, 1989).

From an incentive-based perspective, inventors from both acquired and acquiring firms are likely to have similar incentives at a given time following an acquisition. It is unlikely a firm will be able to offer different incentives (and therefore expect different performance) for the two groups of employees. According to Milgrom and Roberts, when an entrepreneurial firm that emphasizes and rewards initiative is acquired, the bonuses and compensation structures that led to its high preacquisition performance become "regarded as special deals and a source of jealousies" (1992: 575). Milgrom and Roberts cited the example of General Motors managers being angry about bonuses being paid to employees at EDS (which GM acquired); of IBM employees being jealous of the commissions paid to their Rohm counterparts; and of Sony executives feeling similar distress over the compensation of executives in the entertainment businesses that they acquired. Milgrom and Roberts concluded that "as long as the central office of the firm maintains some control over its divisions, the political pressures within the organization to equalize pay and opportunities will be large" (1992: 575).

Hence, the short-run disruption in routines will more severely affect inventors from an acquired firm than inventors from an acquirer. However, per knowledge-based and incentive-based arguments, powerful homogenizing forces will lead these two groups to become more similar over the intermediate and the long term.

Hypothesis 2b. Compared to inventors from the acquiring *firm, the inventors from an acquired firm have lower innovation productivity immediately following the acquisition and similar innovation productivity in the intermediate and the long term.*

A separate issue concerns the level of productivity to which the groups of inventors (the target employees and the acquirer employees) converge. Although it is difficult to draw a conclusion based on theory, it is likely that this level will be lower than that of nonacquired inventors. This argument follows directly from Hypotheses 1 and 2a, which suggest that the productivity of acquired inventors is lower than that of nonacquired inventors and that the gap persists over time. Further, the level at which innovation productivity converges is also likely to be affected by the characteristics and the extent of postacquisition integration of the acquired firms (e.g., Ahuja & Katila, 2001; Puranam et al., 2006). In Hypotheses 3–5 below, we further explore knowledge-based and incentive-based perspectives to identify factors that shape the postacquisition productivity of acquired inventors. In so doing, we illustrate the boundaries of each perspective and how their integration provides a more complete explanation of acquisition outcomes.

Similarity in Routines and Skills

Nelson and Winter (1982) characterized an organization's knowledge as being encapsulated in its skills and routines. Skills refer to the abilities of employees (e.g., training in chemistry or biology), and routines refer to the knowledge by which coordination in an organization is achieved (e.g., the development of new drugs through a collaborative effort among chemists, biologists, statisticians, and doctors). Subsequent scholars have identified various characteristics of organizational routines

(Becker, 2004). However, the examination of skills has been limited. Dosi, Nelson, and Winter (2000) suggested the need to disentangle these variables and examine them in greater detail.

In this study, we consider skills to be the aggregate technical knowledge of the inventors in a firm that manifests itself through research outputs such as patented innovations. We refer to a firm's routines as its "higher-order organizing principles" (Kogut & Zander, 1996) and "knowledge-processing systems" (Lane & Lubatkin, 1998), as determined by the organization's structure, communication channels, and task interdependencies. In our research setting, the most important organizational routines included the processes by which R&D teams managed information and interacted with internal and external partners to create innovative new products. For example, inventors in a semiconductor design firm and a manufacturing firm that we studied had different routines for new-product development. Inventors at the design firm used specialized "EDA" software tools to divide up the task of developing a new circuit and to combine these activities into a computer-based description of the semiconductor chip being produced. They then engaged in a separate set of routines to work iteratively with an external partner to translate their blueprints into a physical product. In contrast, inventors in the manufacturing firm coordinated primarily with other internal R&D teams that specialized in various chemical and fabrication technologies, often piecing together hundreds of different steps into a complete process needed for building a single chip design.

From the knowledge-based perspective, a key consideration is the degree to which the routines of an acquired firm are similar to those of the acquiring firm. Because knowledge is cumulative, it is easier for a firm to absorb external knowledge that is similar or related to its own knowledge base (Grant, 1996; Lane & Lubatkin, 1998). Hence, similarity in the routines acquired and acquiring firms use to coordinate activities should aid the postacquisition innovation productivity of inventors from the acquired firms:

Hypothesis 3. The postacquisition innovation productivity of inventors from an acquired firm is higher if the acquiring firm has similar organizational routines.

In contrast to routines, performance outcomes may have a nonlinear relationship with skills. Similarity in the skills of employees of target and acquiring firms facilitates communication and learning (Bower & Hilgard, 1981; Cohen & Levinthal, 1990; Estes, 1970). However, too much overlap in skills may create redundancies in the combined entity and hence, limit the cross-fertilization of ideas (Ahuja & Katila, 2001). Therefore, we expect that acquisitions characterized by a moderate skill overlap between the acquired and acquiring firms will exhibit a higher level of postacquisition inventor productivity than those characterized by a low or a high degree of skill overlap.

Hypothesis 4. The degree of overlap in the skills of an acquiring and an acquired firm has a curvilinear (inverted U-shaped) relationship with the postacquisition innovation productivity of inventors from the acquired firm.

Unlike in the knowledge-based view, overlapping routines and skills are not key ingredients in agency or property rights theories. A greater overlap between acquiring and acquired firms might improve each party's ability to monitor and evaluate the other's efforts and so reduce contractual hazards (Coff, 1999). However, contractual hazards can only be mitigated to a limited extent, given the high degree of tacit knowledge and intangible effort needed in R&D. Indeed, this uncertainty leads to incomplete contracts being created among the participants involved in the R&D process (Aghion & Tirole, 1994), and hence the incentive-based literature favors trading in intellectual property and other assets needed to commercialize the R&D as solutions to the problem of contractual hazards (Gans, Hsu, & Stern, 2002), rather than better monitoring.

Acquired Firm Size Relative to Acquirer Size

Although several authors have argued that large firms may have greater efficiencies in producing innovations (Kamien & Schwartz, 1982), empirical findings suggest that small firms are more efficient (Acs & Audretsch, 1990; Scherer, 1965; Schmookler, 1972).

Both agency (Holmstrom, 1989) and property rights (Aghion & Tirole, 1994) theories suggest that small firms are better in creating effort-inducing incentives for their R&D employees. Agency loss in large firms is attributable to problems in measuring performance and linking it to employment contracts. Arguments related to property rights have focused on differences in the way innovation-generating assets are used in a large firm as compared to a small firm. Large firms possess internal capital markets to finance projects. The internal capital supplier (e.g., corporate headquarters) is able to exercise a degree of control over projects carried out by a manager. Such control makes it possible for the capital provider to behave opportunistically and therefore distorts the manager's incentives to successfully complete those projects (Gertner, Scharfstein, & Stein, 1994). Supporting the above theories, Zenger (1994) and Zenger and Lazzarini (2004) showed that small firms enjoy advantages compared to large firms with respect to aligning the effort-outcome incentives for R&D employees and measurement of their R&D effort. Hence, if a target firm is acquired by a much larger firm, greater reduction in the incentives of acquired inventors should be observed. In contrast, the greater the size of a target firm relative to an acquirer, the less the reduction in employee incentives.

A related incentive issue is that the greater the size difference between an acquired firm and its acquirer, the greater will be the difference in their compensation systems at the point of merger (Milgrom & Roberts, 1992: 574). The acquiring firm often finds it difficult to retain the performance-based bonuses offered by a much smaller target firm because the bonuses become a source of resentment among employees, and the resolution of this problem diverts attention from productive work, leading employees to connive ways to get better terms for themselves (Milgrom & Roberts, 1992: 575). The above arguments suggest a positive relationship between the size of an acquired firm relative to its acquirer and the postacquisition productivity of the acquired inventors:

Hypothesis 5. The greater the size of an acquired firm relative to its acquiring firm, the greater the postacquisition innovation productivity of inventors from the acquired firm.

The knowledge-based view is less relevant in predicting the effects of the relative size of the acquired firm on inventor productivity. Rather, its applicability is mainly with respect to the ease or difficulty of task coordination and inventive recombination following an acquisition (Hypotheses 3 and 4). The potential for new inventive recombination for the acquired inventors is likely to depend upon the size and the diversity of the acquired firm's knowledge base relative to that of its acquirer (Ahuja & Katila, 2001) rather than on relative overall size. Furthermore, although a greater relative size may increase the integration challenges faced by the acquiring firm (Haspeslagh & Jemison, 1991), the real issue affecting acquired inventors is the degree to which their routines are disrupted and modified, rather than the size differential per se.

METHODS AND DATA

Sample and Data

The sample consisted of inventors working at firms in the semiconductor industry. The innovation productivity of each inventor was measured using patent data, which have been used in numerous studies to measure innovation output (e.g., Ahuja & Katila, 2001). Although imperfect, patent counts are one of the few available measures of innovation output, especially for inventors at privately owned firms (Lim, 2004), such as the ones in our study. Moreover, semiconductor firms have a very high propensity to patent, and they use patents as bargaining chips (Hall & Ziedonis, 2001). This practice reduces the likelihood of missing data resulting from firms choosing to rely on secrecy or copyrights instead of patents as a means of protecting inventions.

We used the Securities Data Corporation (SDC) database, Worldwide Mergers and Acquisitions, to identify acquisitions made by semiconductor firms (SIC code 3674) between 1991 and 1998. The choice of this period was governed by the fact that there were very few acquisitions in the semiconductor industry prior to 1991, and an upper bound of 1998 gave us enough time to observe postacquisition patenting activity. Since patent data were used to observe innovation outcomes, we excluded acquisitions in which the acquired firm did not patent or in which the acquired entity was a business unit rather than an entire firm.[4] We also excluded acquisitions involving non-U.S. firms as these acquisitions present a different set of challenges for both the acquiring and acquired firm owing to greater geographical, institutional, and cultural distance (e.g., Morosini, Shane, & Singh, 1998). The resulting data set comprised 54 acquired firms (out of an initial 209 firms).[5] For each firm, we collected information on the nature of activity it was engaged in prior to the acquisition, the level of integration after the acquisition, the number of employees, and the year the acquired firm was founded. This information was obtained from COMPUSTAT, industry publications, and company reports and press releases.

We identified inventors working at each acquired

[4] The use of patent data did not allow us to identify inventors working in business units, as patents are typically assigned to the parent firm.

[5] An important assumption in this study is that the decisions to acquire other firms were at least partly driven by the technological resources of the acquired firms. We collected press announcements for the firms in our sample. In almost every case, the technology and knowledge bases of the acquired firms were key issues mentioned by representatives of the acquiring firms. Moreover, since all these firms had actively patented in the five years preceding acquisition, technological resources were likely to be important to the acquired firms' competitive positions.

firm by examining U.S. patents awarded between 1976 and 2004 to these firms. An inventor was included if he or she had had at least one patent granted with an acquired firm as an assignee, prior to the acquisition of that firm. After obtaining the names of these inventors, we collected the complete patenting history for each, including dates of patents, firms worked at, geographic locations, and technological areas of innovation.

An important methodological issue was identifying a suitable cutoff date separating preacquisition from postacquisition patents. We used the date when an acquisition transaction was completed, not when it was announced. We expected a short delay (of several months) between the creation of an invention and the patent application date. Using the announcement date would have increased the likelihood of inventions created before acquisition inadvertently being counted as part of postacquisition outcomes. By starting the evaluation window from the completion date of the acquisition, we were being conservative in our postacquisition innovation measure. Furthermore, all except two acquisitions in our data set had been completed within six months of their announcement dates, with the average completion time being 74 days. We performed robustness checks on the inventors from the two acquired firms that took more than six months, and the results remain largely unchanged.

Another methodological concern was that several different inventors might have the same name. To maximize the probability that an observed inventor was the same as an inventor identified in an acquired firm, we compared the first and last names and middle initial (if available) for exact matches and verified that the temporal, geographic, and technological information mentioned in patent records revealed no inconsistencies. After completing the process of inventor identification, we screened the data to exclude inventors who had patent records with other firms prior to focal acquisitions, as this condition would suggest that he or she had already left the acquired firm before the acquisition. We also excluded inventors who had not received any patents with an acquired firm over the five years prior to the acquisition date. It is likely that such an individual had retired from the firm or moved on to a management position by the time of acquisition. Since our aim was to examine the productivity of inventors after their firm's acquisition, we excluded inventors who patented with other firms within five years after the acquisition. The final sample consisted of 318 inventors from 50 firms acquired during the period 1991–98.

Construction of Control Groups

Testing Hypotheses 1, 2a, and 2b presented several challenges. We needed to isolate the effect of acquisitions on the innovation productivity of each inventor while accounting for other factors that might affect inventor productivity. As Levin and Stephan (1991) showed, scientists exhibit a life cycle effect: their innovation productivity declines as their careers progress. Hence, it is insufficient to show that inventors at acquired firms produced fewer inventions than before, but that the rate of decay was significantly different from that expected as a result of the life cycle effect. Moreover, firms are heterogeneous in their propensities to innovate, because of variations in technological opportunity and appropriability (Dosi, 1988). Firms also have different propensities to patent, and this in turn may depend upon variation in strategic response to "hold-up" problems (Hall & Ziedonis, 2001).

We carefully matched each acquired inventor with inventors from two separate control groups. Our first control group was composed of inventors from similar semiconductor firms that were *not* acquired during the period of study. The creation of this control group allowed us to examine Hypotheses 1 and 2a. We identified these firms by the nature of their product-markets (e.g., microprocessors, graphics chips), their business activities (e.g., semiconductor design, integrated device manufacture) and the presence of a patent citation link (one firm citing the other firm's patents). Firms competing in the same product-market and having similar activities are likely to have similar technological opportunity and appropriability from their innovations (Dosi, 1988). Hence, the inventors in these firms are likely to have similar incentives and opportunities to innovate. In addition, a patent citation link between two firms further indicates that they are technologically related (Rosenkopf & Almeida, 2003).

Each inventor from an acquired firm was matched to an inventor from a control firm using a lexicographic criterion designed to find an inventor who was technologically proximate to an acquired inventor, at the same stage of the life cycle, and similar in innovation productivity in the period before acquisition. The identification procedure included searching for inventors in a control firm who received patents in the same technological field, as defined by each patent's primary three-digit class. Among these inventors, we identified those who were at a similar life cycle stage at the time of acquisition (i.e., the time lag between receipt of a first patent and the date of acquisition). We called this life cycle variable an inventor's "innovation age." We identified inventors at the control firm with innovation ages "as close as possi-

TABLE 1
Description of Variables[a]

Variable Name	Description
Dependent variable	
Postacquisition innovation	The total number of granted patents filed by an inventor with a focal firm in a given year after a relevant acquisition date.
Independent variables	
Routines overlap	A dummy coded 1 if an acquired firm and its acquiring firm participated in similar activities in the semiconductor industry (i.e., they fall into the same category in Table 2); 0 otherwise.
Skills overlap	The degree of overlap between the granted and cited patents of an acquired firm and those of its acquiring firm, prior to the acquisition.
Relative size	The ratio between the numbers of employees of an acquired firm and its acquiring firm in the year of the acquisition.
Acquired	A dummy coded 1 for inventors from an acquired firm and 0 otherwise.
Control variables	
Integration	A dummy coded 1 if an acquired firm was integrated into the operation of its acquiring firm and 0 otherwise; based on news reports and press releases.
Preacquisition productivity	The total number of granted patents filed by an inventor with a focal firm within five years before relevant acquisition date.
Inventor tenure	The difference in years between the date when the inventor filed a first patent with a focal firm and the year in which the postacquisition innovation is observed.
Acquired firm age	The age of a target firm at the time of its acquisition.

[a] For acquired inventors, "focal firm" refers to their acquired firm for preacquisition productivity and inventor tenure and to the acquiring firm for postacquisition innovation. For inventors from the nonacquired and acquiring control groups, "focal firm" refers to the nonacquired and acquiring firms, respectively.

ble"[6] to those of inventors at the acquired firms. We completed the matching by selecting the inventors with the closest[7] innovation productivity, as measured by numbers of patents prior to the acquisitions. Finally, as with our main sample, we excluded inventors who had patented with other firms during the period of study after the acquisition.

We used the same methodology to construct a second control group, composed of inventors from the acquiring firms, to examine Hypothesis 2b. The use of a control group was especially important in this case because, prior to acquisition, the average inventor from an acquired firm is likely to have a different level of productivity than the average inventor from an acquiring firm. The matched-pair design allowed us to compare each acquired inventor with a corresponding "acquiring inventor" having similar preacquisition characteristics. The matching of inventors from acquiring firms resulted in 287 inventors from 50 firms, and the matching of inventors from nonacquired firms resulted in 259 inventors from 45 firms.

Measures

Table 1 lists and defines the variables used in this study, which are further described below.

Dependent variable. We observed each inventor's postacquisition innovation productivity for five years after an acquisition.[8] Our dependent variable was the number of successful patent applications filed by an inventor in a given year after acquisition while working for the acquiring firm. Ideally, we would have preferred to include citation counts to control for the quality of each patent (Jaffe & Trajtenberg, 2002). However, we were limited by the length of our study period, which did not allow adequate time lags for reliably observing citations to the focal patents. To test robustness, we

[6] The algorithm we used searches for a matched inventor using an upper bound of *twice the innovation age* and a lower bound of *half the innovation age* of the acquired inventor. The innovation age in this algorithm was a count variable in years. We also conducted robustness checks by reducing the upper bound to 1.5 times the acquired inventor's innovation age, and results were similar to those reported in the paper.

[7] The algorithm we used searches for a matched inventor using an upper bound of *twice the number of patents* and a lower bound of *half the number of patents* by the acquired inventor. We also conducted robustness checks by reducing the upper bound to 1.5 times the acquired inventor's preacquisition patent count; the results were similar to the ones reported.

[8] The choice of the five-year window was limited by the availability of patent data up to 2004. We also conducted robustness tests by using three-year and four-year windows.

constructed an additional innovation measure: patent counts for each inventor during the first two years after the acquisition weighted by the number of citations received within three years from the grant date. We found the results to be consistent with the ones reported here.

Independent variables. We examined the effect of two different levels of knowledge within firms. The first level, organization skills, identified the type of skills possessed by individuals in a firm, and the second level, organization routines, identified the type of coordination activities undertaken by the firm. To measure the degree to which the skills of an acquiring firm were similar to those of a target firm, we employed a variable introduced by Ahuja and Katila (2001). They defined a firm's knowledge base as the list of patents obtained by that firm's inventors five years prior to acquisition plus all backward citations (citations to earlier patents) made in those patents. For each acquired firm, they then measured the relatedness of its acquired knowledge base as the proportion of its knowledge base that was the same as the acquiring firm's. For brevity, we named this variable *skills overlap* in our investigation, calculating it as the number of patents and backward patent citations common to an acquiring and acquired firm prior to acquisition divided by the number of patents and backward citations of the acquired firm prior to acquisition. For example, if an acquiring firm's knowledge base consisted of patents A and B and a citation to patent C, and the acquired firm's knowledge base consisted of patents D and E and citations to patents C and F, then patent C is common to both, and skills overlap has a value of one-quarter (¼).

We constructed a second variable, *routines overlap*, by identifying whether target and acquiring firms undertook the same type of activity in the semiconductor industry. Firms pursuing similar activities are likely to have similar coordination routines embedded in their organizational structures (DiMaggio & Powell, 1983), task interdependencies, and communication patterns (Galbraith, 1973, 1977). Prior research in the semiconductor industry has shed light on the coordination mechanisms undertaken by integrated device manufacturers (IDMs), which are firms that both design and manufacture semiconductors, versus those of "fabless" firms, which design semiconductors but outsource manufacturing. Monteverde (1995) provided a useful description of the differences in how engineers in IDMs and engineers in fabless firms communicate to create new products. Engineers in IDMs were found to have significantly more unstructured technical dialog during product development stages than engineers in fabless firms.

We conducted interviews with industry participants to better understand the product development routines of the firms organized around different type of activities. A veteran engineer who had worked with both an IDM and a fabless firm clearly identified the similarity in routines within a category and differences between categories: "In IDMs, a new design is developed in collaboration with the firm's manufacturing division whereas in fabless firms, you have more flexibility to create the design and then work with external manufacturing partners to ensure its commercialization."

Although the contrast between IDM and fabless firms is important, additional interviews and industry reports suggested that a finer classification was appropriate. Acquisitions in the semiconductor industry involve not just IDMs and fabless firms, but also a range of specialized firms such as equipment suppliers, system manufacturers, software developers, and materials suppliers. These firms help to manage the high degree of complexity and sustain technological innovation in this industry (Baldwin & Clark, 2000). Technological architectures differ among activities in the semiconductor industry, leading to different communication channels, information filters, and problem-solving routines (Henderson & Clark, 1990). Thus, we grouped firms into one of the activity categories listed in Table 2.[9] The variable *routines overlap* was set to 1 if an acquiring and acquired firm fell into the same category and to 0 otherwise. We assumed that each category was equally different from the others in constructing this measure. This is clearly an oversimplification, but we believe that our classification scheme is adequate to test the validity of our arguments.

The variable *relative size* (Table 1) was measured by dividing the number of employees in the target firm the year the acquisition took place by the number of employees in the acquiring firm that year. The multivariate test of Hypotheses 1, 2a, and 2b was performed using the variable *acquired*, which takes a value of 1 for inventors from the acquired firms and 0 otherwise.

Control variables. In our regression models, we controlled for both individual-level (inventor-level) and firm-level effects. We controlled for the *preacquisition productivity* of inventors by obtaining the number of patents awarded to each inventor over the five years prior to the acquisition. Ahuja and Katila (2001) also used a five-year preacquisi-

[9] Similar schemes are used by industry participants and analysts, including the Semiconductor Equipment and Materials International (SEMI®) and Gartner Dataquest.

TABLE 2
Categorization of the Firms Used in the Study[a]

Category	Description of Activity
Integrated device manufacturer	A vertically integrated organization that designs and manufactures semiconductors.
Fabless semiconductor	An organization that designs semiconductors but partners with external specialized firms to manufacture the semiconductors.
Semiconductor system manufacturer	An organization that designs and manufactures semiconductor subsystems or assemblies.
Semiconductor manufacturing equipment supplier	An organization that designs and manufactures equipment for semiconductor manufacturing.
Semiconductor materials supplier	An organization that develops and supplies materials for semiconductor manufacturing.
Contract design services provider	An organization that provides design services for semiconductor design.
Software developer	An organization that develops software code for semiconductor applications.

[a] The categorization scheme is similar to the one used by the industry body, Semiconductor Equipment and Materials International (SEMI; www.semi.org).

tion window because technological knowledge depreciates rapidly and loses most of its value within that time (Griliches, 1979). To account for changes in an inventor's productivity during the period of employment by an acquired firm, we computed *inventor tenure*, which was the number of years between the date an inventor filed for his or her first patent with an acquired firm as assignee and the year of observation for the postacquisition innovation outcome. To control for the resilience of a firm's routines (Hannan & Freeman, 1984) after an interruption (Zellmer-Bruhn, 2003), we controlled for an *acquired firm's age* at the time of acquisition.

We also controlled for the degree of postacquisition *integration*. An acquiring firm may integrate an acquired firm tightly into its organization or leave it relatively independent (Haspeslagh & Jemison, 1991). Low integration is limited to the standardization of basic management systems and processes to facilitate communication. High integration involves extensive sharing of resources (financial, physical, and human), adoption of the same operating and control systems, and structural and cultural absorption of the acquired firm. Although integration may help in the reconfiguration of resources (Capron, 1999; Capron, Dussauge, & Mitchell, 1998), it may also disrupt organizational routines (Puranam et al., 2006) and lead to a loss of autonomy among employees (Ranft & Lord, 2002). We assigned the variable integration a value of 1 if an acquired firm was integrated into the operation of the acquiring firm. It was set to 0 if the acquired firm was maintained as a separate business unit or a subsidiary within the acquiring firm.

Analysis

We tested Hypotheses 1, 2a, and 2b by comparing the annual innovation productivity of inventors at acquired firms with that of the two control groups (inventors from nonacquired firms and acquiring firms). We used a two-tailed matched pair *t*-test as well as a less restrictive nonparametric Wilcoxon signed-rank test. The application of the univariate test hinged upon the careful construction of the control groups, which helped to account for various other influences on postacquisition inventor performance. We believe that our quasi-experiment using a pre- and posttest design with a comparable control group provided a strong case of causal inference (Shadish, Cook, & Campbell, 2002). To check the robustness of the univariate test, we also report multivariate regression results for inventor's productivity in a given year after an acquisition.

Hypotheses 3–5 were tested using regression models. Since our dependent variable was a count variable, a Poisson regression approach was appropriate. However, the variable exhibited overdispersion and violated the Poisson assumptions. Hence, we employed a negative binomial model (Hausman, Hall, & Griliches, 1984). In addition, our dependent variable exhibited excess zeros. We used preacquisition patenting activity over a period of five years to identify the "active" inventors in the acquired firms. This may have resulted in the inclusion of inventors who were not active with the focal firm at the time of acquisition. For example, an inventor might have obtained a patent four years before an acquisition but not have received any patents subsequently. This could have resulted from an inventor becoming unproductive prior to the acquisition because of assuming other roles in the firm (e.g., becoming a manager or working on product commercialization) or leaving the firm.

The effect of excess zeros would be misspecification of the negative binomial model. We thus used a zero-inflated negative binomial (ZINB) regression model (Greene, 2000; Long, 1997), estimating the probability of postacquisition innovation through a logit model before estimating the negative binomial model. The zero-inflation parameters used were the number of successful patents filed by an inventor prior to an acquisition, the number of years the inventor was active before the acquisition, measured using his or her patenting activity, and the acquired firm fixed effects. These factors are likely to influence the likelihood that an inventor continues to produce a nonzero number of patents with the acquired firm. In our case, the Vuong statistic (Vuong, 1989) showed that the ZINB model was more appropriate than the negative binomial model. To check robustness, we also estimated a single-equation negative binomial model. Note that it is also difficult to determine whether observed overdispersion is indeed due to the distribution of the data or an artifact of the regime-splitting mechanism used (Greene, 2000: 890). In the latter case, a zero-inflated Poisson (ZIP) model is appropriate (Lambert, 1992). Hence, we used ZIP regressions to further test the robustness of our results.

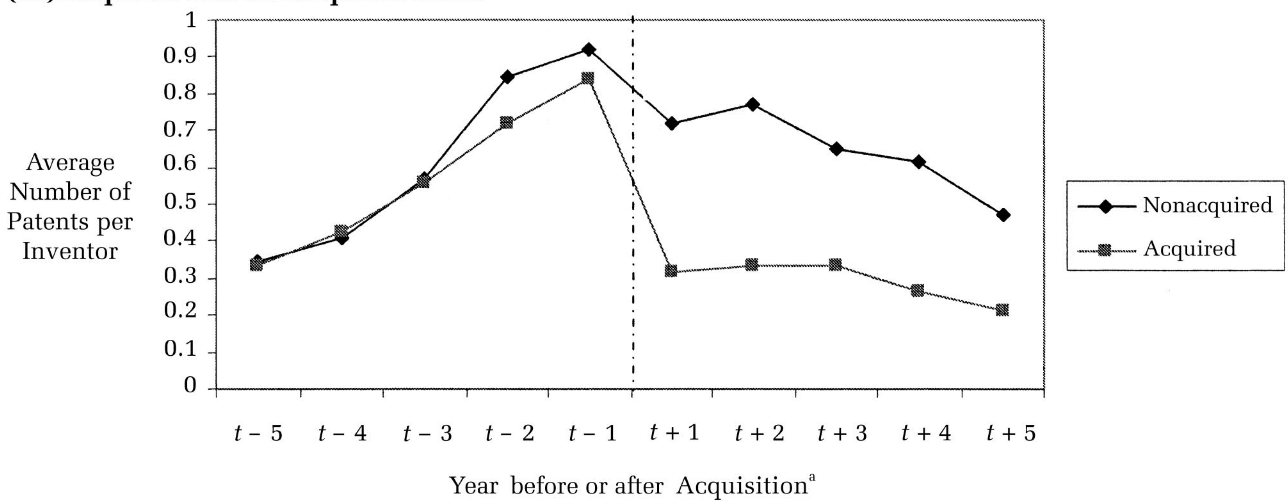
RESULTS

Univariate Tests for Hypotheses 1, 2a, and 2b

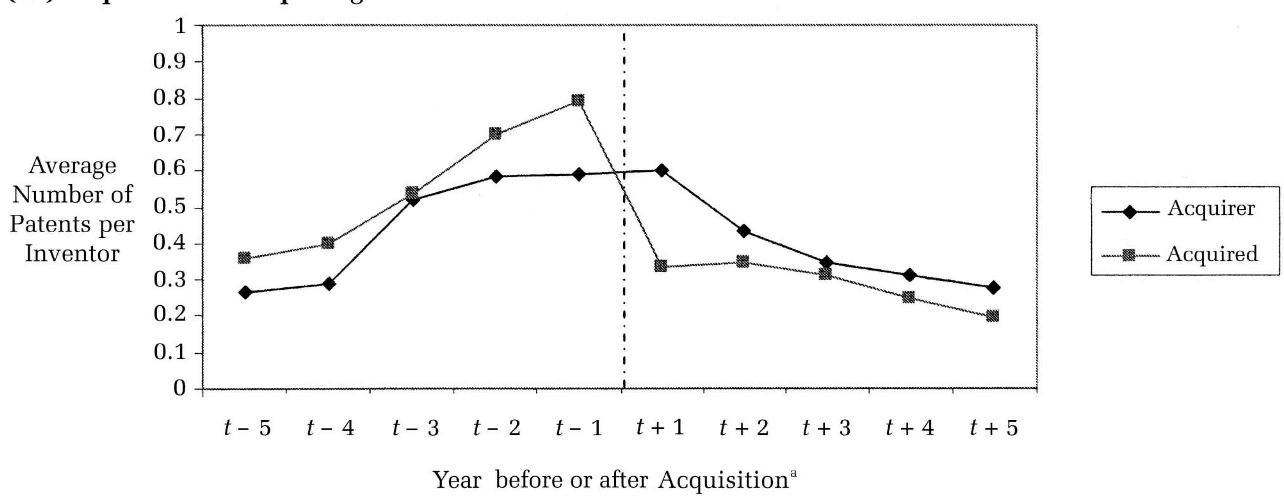
Figures 1a and 1b depict an intuition for the results of tests of Hypotheses 1, 2a, and 2b. Figure

FIGURE 1
Comparisons of the Pre- and Postacquisition Innovation Productivity of Inventors from the Study and Control Samples

(1a) Acquired and Nonacquired Firms



(1b) Acquired and Acquiring Firms



[a] *t* is the day of an acquisition event; *t*+ (−) *X*th year implies the *X*th year after (before) acquisition. For example, *t* +2 is the period of observation during the second year after acquisition.

1a shows that relative to inventors at nonacquired firms, those at acquired firms exhibit a sharp drop in productivity immediately following the acquisitions. This finding is consistent with Hypothesis 1. The figure also shows that the lower productivity of acquired inventors persists over time, a finding that is consistent with Hypothesis 2a. For the first through the fifth years after acquisition, the innovation productivity of acquired inventors was more than 50 percent lower than that of the nonacquired group. Figure 1b shows that, relative to inventors at acquiring firms, the productivity of inventors from acquired firms was markedly lower in the aftermath of acquisition, but they subsequently track each other fairly closely.

Table 3a compares the innovation productivity (number of patents per year) of inventors from acquired firms with that of inventors at nonacquired firms. Prior to acquisition, matched-pair *t*-tests show no significant difference, with the means being statistically similar over groups. The nonparametric Wilcoxon signed-rank test also shows almost no difference in the preacquisition performance of acquired inventors and those from the nonacquired firms (except in the second year before acquisition, which is probably just an aberration).

Interestingly, the results are quite different after acquisition. The acquired inventors exhibited significantly lower innovation productivity between the first and fifth years after acquisition than their

TABLE 3
Comparisons of the Innovation Productivity of Inventors from the Study and Control Samples[a]

(3a) Acquired and Nonacquired Firms

Year[b]	Mean Innovation Productivity: Acquired	Mean Innovation Productivity: Nonacquired	*t*-statistic[c]	Signed-Rank *Z*-statistic[c]
$t - 5$	0.33	0.35	−0.31	0.02
$t - 4$	0.42	0.41	0.20	−0.55
$t - 3$	0.56	0.57	−0.17	0.03
$t - 2$	0.72	0.84	−1.36	−2.19*
$t - 1$	0.84	0.92	−0.76	0.26
$t + 1$	0.32	0.72	−3.91***	−4.38***
$t + 2$	0.33	0.77	−4.38***	−4.39***
$t + 3$	0.34	0.65	−3.81***	−3.48***
$t + 4$	0.27	0.62	−3.94***	−3.65***
$t + 5$	0.21	0.48	−2.74**	−2.24*

(3b) Acquired and Acquiring Firms

Year[b]	Mean Innovation Productivity: Acquired	Mean Innovation Productivity: Acquiring	*t*-statistic[c]	Signed-Rank *Z*-statistic[c]
$t - 5$	0.36	0.26	1.72†	2.08*
$t - 4$	0.40	0.29	1.81†	1.85†
$t - 3$	0.54	0.52	0.22	1.26
$t - 2$	0.70	0.59	1.31	0.36
$t - 1$	0.79	0.59	2.45*	2.27*
$t + 1$	0.33	0.60	−3.17**	−4.73***
$t + 2$	0.35	0.44	−1.09	−1.10
$t + 3$	0.31	0.35	−0.59	−0.03
$t + 4$	0.25	0.31	−0.90	0.04
$t + 5$	0.20	0.28	−1.10	−0.85

[a] $n = 259$ matched inventors from acquired and nonacquired firms and 287 matched inventors from acquired and acquiring firms.

[b] t is the day of an acquisition event; t + (−) Xth year implies the Xth year after (before) acquisition. For example, $t + 2$ is the period of observation during the second year after acquisition.

[c] All reported *t*-statistic and signed-rank *Z*-statistics are based on the difference in innovation productivity between the matched acquired and nonacquired/acquirer inventor.

† $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$
Two-tailed tests.

matches from the nonacquired group. Hence, the lower productivity of acquired inventors relative to nonacquired inventors is not only significant, but also persists for five years (Hypothesis 2a). The results provide strong support for Hypotheses 1 and 2a. We also observe an overall decline in the mean innovation productivity of both the acquired and nonacquired inventors, which is consistent with inventor life cycle effects and further validates the importance of our research design.[10]

The lower portion of Table 3, Table 3b, shows the results of using inventors from acquiring firms as the comparison group instead of inventors from nonacquired firms. In the year following acquisition, the innovation productivity of acquired inventors becomes lower than that of inventors from the acquiring firm ($t = -3.17$ in year $t + 1$). However, from the second postacquisition year onwards, the difference between inventors at acquiring and acquired firms becomes statistically insignificant. Therefore, inventors from acquired and acquiring firms have similar productivity levels in the intermediate and the long term. Results derived with the Wilcoxon signed-ranked test were similar. If the preacquisition productivity of acquiring and matched acquired inventors were similar, the above result would imply support for Hypothesis 2b. However, this assumption is violated, and Table 3b shows that the acquired inventors were more productive than their matched counterparts in the fifth, fourth, and first years before acquisition. This problem arises because our matching algorithm is limited by a lack of inventors from acquiring firms with suitably close preacquisition productivity. Although we were unable to fully validate the reasoning for Hypothesis 2b for the second postacquisition year and onward (the acquired inventors could have been less productive than acquiring inventors absent the preexisting differences in productivity), in the Appendix we show that the results given in Table 3b allow for a weaker interpretation: following an acquisition, acquired inventors face greater disruption to their routines than those from the acquiring firms. This interpretation builds on the condition that preacquisition productivity has a positive effect on postacquisition performance, which is consistent with results presented in Tables 4b and 6 below.

Multivariate Tests

We also examined Hypotheses 1, 2a, and 2b using a ZINB specification. We controlled for each inventor's tenure with an acquired firm as well as her or his preacquisition productivity. The results were consistent with our findings from the univariate tests and are reported in Tables 4a and 4b. In Table 4a inventors from nonacquired firms are the comparison group, and in Table 4b inventors from acquiring firms are the comparison group. The estimated coefficient for the variable "acquired" in Table 4a is negative and significant for each of the five years after acquisition. Hence, the acquired inventors exhibited significantly lower innovation productivity than the nonacquired ones over those years (Hypotheses 1 and 2a). However, in the lower part of the table, the negative and significant coefficient for "acquired" for the two years after an acquisition (-0.63 in year $t + 1$ and -0.35 in year $t + 2$) becomes insignificant thereafter from year $t + 3$ to year $t + 5$. Thus, compared to inventors from the acquiring firms, acquired inventors were significantly less productive in the first two years after acquisition, but subsequently, there was no productivity difference (Hypothesis 2b). An additional specification that included acquirer firm fixed effects yielded similar results.

The effects of the control variables were as expected. Inventors who were productive prior to acquisition remained productive afterward, although the effect decays over time. *Inventor tenure*, however, was negatively associated with productivity, as is consistent with the expected career life cycle of inventors.

Regression Analysis for Hypotheses 3–5

Table 5 shows the descriptive statistics and correlations for the variables used to test Hypotheses 3–5. As expected, the postacquisition innovation of inventors is correlated with preacquisition productivity. A negative correlation exists between routines overlap and skills overlap, suggesting that acquired and acquiring firms having similar routines might not have similar skills. This finding may be related to the complementarities between firms that motivate acquisitions.

Table 6 presents our main regression results. Model 1 is the base model. The independent variables were added hierarchically in models 2, 3, 4 and 5. A likelihood-ratio test shows that the addi-

[10] To ensure that career life cycle effects were controlled for in the matched groups, we compared the time periods during which each inventor was active prior to an acquisition. We found no significant differences: t was -0.06 when we compared acquired and acquirer inventors, and t was -0.28 when we compared acquired and nonacquired inventors.

TABLE 4
Zero-Inflated Negative Binomial Regression Results for the Postacquisition Innovation Productivity of Inventors from the Study and Control Samples, by Year[a]

(4a) Acquired and Nonacquired Firms

Variable	t + 1		t + 2		t + 3		t + 4		t + 5	
Acquired	−0.52**	(0.20)	−0.77***	(0.20)	−0.43*	(0.19)	−0.65**	(0.25)	−0.61*	(0.28)
Preacquisition productivity	0.11***	(0.03)	0.15***	(0.04)	0.06*	(0.03)	0.05	(0.04)	0.01	(0.03)
Inventor tenure	−0.05	(0.04)	−0.14***	(0.04)	−0.07*	(0.03)	−0.01	(0.04)	−0.04	(0.04)
Constant	0.03	(0.26)	0.12	(0.28)	0.36	(0.27)	0.01	(0.39)	0.50	(0.43)
Observations	518		518		518		518		518	
Log-likelihood	−402.40		−448.73		−417.16		−384.34		−317.91	
Incremental chi-square[b]	6.70**		15.11***		5.41*		6.79**		5.47*	

(4b) Acquired and Acquiring Firms

Variable	t + 1		t + 2		t + 3		t + 4		t + 5	
Acquired	−0.63**	(0.20)	−0.35†	(0.21)	−0.04	(0.21)	0.07	(0.26)	0.03	(0.27)
Preacquisition productivity	0.14***	(0.03)	0.09**	(0.03)	0.05	(0.03)	−0.01	(0.03)	−0.02	(0.03)
Inventor tenure	−0.08**	(0.03)	−0.06*	(0.03)	−0.08*	(0.03)	−0.11*	(0.05)	−0.13**	(0.04)
Constant	−0.12	(0.20)	−0.02	(0.27)	0.10	(0.26)	1.09**	(0.32)	0.96*	(0.39)
Observations	574		574		574		574		574	
Log-likelihood	−441.29		−402.87		−357.76		−290.57		−259.32	
Incremental chi-square[b]	10.17**		2.78†		0.03		0.07		0.01	

[a] Standard errors are in parentheses. t is the day of an acquisition event; $t + X$th year implies the Xth year after acquisition. For example, $t + 2$ is the period of observation during the second year after acquisition.
[b] Vis-à-vis the base model, without the effect of acquisition being examined.
† $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$
Two-tailed tests.

TABLE 5
Descriptive Statistics and Pairwise Correlations for Inventors from Acquired Firms[a]

Variables	Mean	s.d.	Minimum	Maximum	1	2	3	4	5	6	7
1. Postacquisition innovation productivity	0.29	0.89	0.00	17.00							
2. Routines overlap	0.47	0.50	0.00	1.00	.08*						
3. Skills overlap	0.11	0.13	0.00	0.71	.00	−.52*					
4. Relative size	0.17	0.20	0.00	0.81	.02	.37*	−.41*				
5. Integration	0.34	0.47	0.00	1.00	.02	.31*	−.17*	.29*			
6. Preacquisition productivity	2.85	3.12	1.00	21.00	.26*	−.11*	−.02	−.10*	−.02		
7. Inventor tenure	6.43	3.06	1.05	24.65	−.01	−.08*	.15*	.12*	−.04	.16*	
8. Acquired firm age	9.59	4.78	2.00	40.00	.03	.20*	.22*	.27*	.36*	−.10*	.24*

[a] $n = 1{,}590$.
* $p < .05$

tion of our main independent variables significantly improves the model fit. The estimated coefficient for routines overlap is positive and significant in all models, supporting Hypothesis 3, stating that inventor productivity is greater if acquired and acquiring firms have similar coordinating routines. The impact of skills overlap on inventor productivity is evaluated in models 3 through 5. Although this variable has a positive effect on the postacquisition productivity of acquired inventors, the effect of skills overlap squared is negative. The squared term is statistically significant in model 5. Hence, the results support Hypothesis 4, in that inventor productivity has a curvilinear (inverted U-shaped) relationship with skills overlap. Model 5 tests for the effect of the relative size of an acquired

TABLE 6
Zero-Inflated Negative Binomial Regression Results for Acquired Inventors' Postacquisition Innovation Productivity[a]

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Independent					
Routines overlap		0.66*** (0.17)	1.08*** (0.23)	1.21*** (0.26)	1.32*** (0.27)
Skills overlap			2.25* (0.89)	3.99* (1.86)	6.52** (2.13)
Skills overlap squared				−2.98 (2.80)	−5.45† (2.92)
Relative size					1.38* (0.58)
Control					
Preacquisition productivity	0.06** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)
Inventor tenure	−0.09*** (0.02)	−0.09*** (0.02)	−0.07** (0.02)	−0.08** (0.02)	−0.09*** (0.02)
Firm age	0.12*** (0.02)	0.10*** (0.02)	0.06* (0.03)	0.06* (0.03)	0.02 (0.03)
Integration	−0.77*** (0.21)	−0.92*** (0.20)	−0.65** (0.21)	−0.65** (0.21)	−0.62** (0.21)
Regression statistics					
Constant	−0.69** (0.26)	−1.05*** (0.26)	−1.43*** (0.27)	−1.51*** (0.28)	−1.62*** (0.28)
Observations	1,590	1,590	1,590	1,590	1,590
Log-likelihood	−829.13	−819.16	−816.17	−815.60	−812.77
Incremental χ^2		19.94***	5.98*	1.14	5.66*

[a] Standard errors are in parentheses.
† $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$
Two-tailed tests.

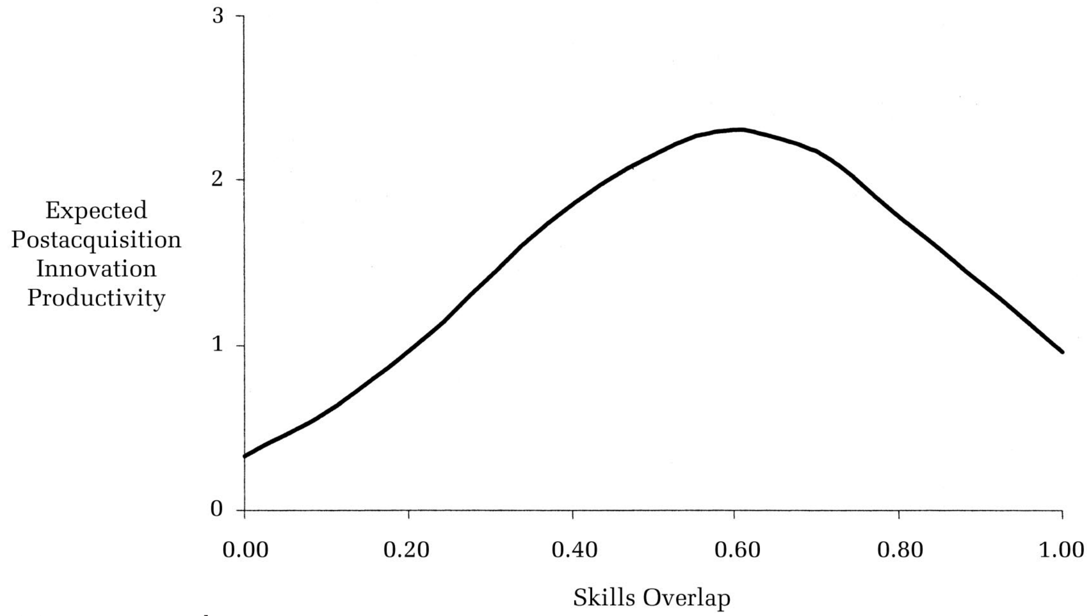
firm. The significant and positive coefficient supports Hypothesis 5: inventors from acquired firms that are not small in comparison to the acquiring firms exhibit greater postacquisition innovation productivity.

As for the control variables, we found that an inventor's preacquisition productivity correlated with postacquisition productivity. Life cycle effects are important, with inventor tenure having a negative impact on postacquisition productivity. The effect of acquired firm age on inventor productivity is positive but only significant in some specifications, providing some support for the idea that older firms possess more resilient innovation routines than younger firms (Hannan & Freeman, 1984). Finally, postacquisition integration has a negative and significant effect on the postacquisition innovation of acquired inventors.

Although we found support for Hypothesis 4 (the inverted U-shape for skills overlap), our results are not as strong as for the other independent variables. In Table 6, the coefficient for skills overlap is positive and significant in all specifications, but that for the squared term is marginally significant after relative size is taken into account (model 5). Figure 2 shows a graph of the quadratic relationship between skills overlap and the expected postacquisition innovation for an "average" inventor. Since we used a nonlinear specification, we could not simply plot the coefficients reported in Table 6. We followed Cameron and Trivedi (1998: 80) and plotted conditional postacquisition innovation for an acquired inventor having mean characteristics against that inventor's skills overlap. Figure 2 resembles an inverted "U": at the vertical axis where skills overlap equals 0, the expected innovation output is 0.3 patents per year, which increases to a peak of around 2.2 when skills overlap is 0.6 and declines to 1.0 when skills overlap is maximal. These changes are substantial in relation to the mean postacquisition innovation level of 0.29 patents per year in Table 5 (this is the mean value of the raw data and includes excess zeros, so it appears low relative to the predicted values). Overall, our results are consistent with prior firm-level studies examining knowledge overlap between acquired and acquiring firms (Ahuja & Katila, 2001; Prabhu, Chandy, & Ellis, 2005).

We performed three additional robustness tests for our regression results. First, we used the ZIP model instead of the ZINB model to ensure that the hypotheses hold even if the counts were generated as a result of Poisson process. The results remained qualitatively unchanged for all our key independent variables. Second, we tested our data using a negative binomial model. The coefficients for the hypothesized variables exhibited the predicted signs. However, statistical significance was not achieved for skills overlap and relative size. This result was expected since the presence of excess

FIGURE 2
Predicted Effect of Similarity of Skills Overlap on Inventor's Postacquisition Innovation Productivity[a]



[a] Productivity was measured as patents per year.

zeros causes large standard errors for the independent variables. Finally, we evaluated the sensitivity of using a five-year postacquisition window by using three- and four-year windows instead. The results are consistent with the ones reported here.

DISCUSSION AND CONCLUSIONS

Our study contributes to an important debate among management scholars on the role of incentives and knowledge resources in shaping firm performance (Foss, 1996a, 1996b; Kogut & Zander, 1992, 1996; Williamson, 1999). We stitch together elements of incentive theory and the knowledge-based view to show how they complement each other in explaining the postacquisition performance of inventors. We also clarify the different dimensions along which each perspective is useful, and we demonstrate how these approaches are tightly interwoven.

Consistently with both perspectives, we find evidence that the productivity of acquired inventors is lower than that of inventors at nonacquired firms following an acquisition. Incentive-based theories explain why their productivity persists below the level for nonacquired inventors. The knowledge-based view accounts for a temporary (one- to two-year) disruption in productivity relative to inventors from their acquiring firm, and both perspectives jointly predict the subsequent similarity in the performance of these groups. These findings suggest that the knowledge and incentive-based perspectives are not necessarily at odds with one another.

We further show how each perspective emphasizes distinct determinants of postacquisition inventor productivity. The knowledge-based perspective accounts for a positive relationship between routines overlap and inventor performance, as well as for an inverted U-shaped relationship between skills overlap and performance, highlighting an important difference between skills and routines as key constituents of firm knowledge (Dosi et al., 2000). The incentive-based approach predicts a positive correlation between the relative size of an acquired firm and postacquisition inventor performance.

Although our results are robust in showing that acquired inventors have lower postacquisition productivity than nonacquired ones, several deeper factors could be driving this result. The simplest possibility is that acquisitions adversely affect the productivity of acquired inventors. This is consistent with the failure of mergers and acquisitions reported in the literature and suggests that the desired synergy from combining the knowledge resources of two separate firms is quite elusive. A second possibility is that acquiring firms are able to capture value from acquisitions through other (nonpatent) means. For example, Nicholls-Nixon and Woo (2003) reported that the acquisition of biotechnology firms by pharmaceutical ones resulted in an increase in new biotechnology-based products but did not have a significant effect on patent output. It is plausible that an acquisition reduces acquired inventors' patent productivity but is

TABLE 7
Proportion of Inventors Who Were Productive during the Five Years after Acquisition[a]

Status	All Inventors			Star Inventors[b]		
	Acquired	Acquiring	Nonacquired	Acquired	Acquiring	Nonacquired
Productive, left the acquired firm	14	15	13	15	13	19
Productive, stayed at the acquired firm	31	38	46	29	51	49
Unproductive	55	47	41	56	36	32

[a] An inventor was considered productive if he or she had at least one patent granted within five years after the acquisition of the acquired firm.
[b] Star inventors are the top 20 percent of inventors from a firm in terms of the number of granted patents filed within five years before the acquisition.

still worthwhile if it strengthens the intellectual property portfolio of the acquiring firm, or allows it to use the acquired knowledge to generate new products. Unfortunately, our empirical design did not permit a deeper examination of this alternative explanation, and we suggest it as a future research opportunity.

A separate issue concerns employee retention as one of the key challenges facing acquiring firms (Ernst & Vitt, 2000; Ranft & Lord, 2000, 2002). Retention may be a difficult problem in other contexts, but we found that the acquirers in our sample were generally successful at retaining acquired inventors. As shown in Table 7, inventors who were productive after acquisitions were *not* more likely to leave an acquirer than our control groups (14 percent for inventors from the acquired firms versus 15 percent and 13 percent for inventors from the acquiring and the nonacquired firms, respectively). This result is consistent with those of Mayer and Kenney (2004), who reported that retention issues had become a key priority for high-tech acquirers such as Cisco. However, compared to the control groups, a much greater proportion of acquired inventors became unproductive. This result was particularly pronounced for "star" inventors, whom we defined as the top 20 percent from each firm.[11]

A final but important concern is endogeneity: could a strategic choice purposefully lead to both acquisition and reduced innovation among acquired inventors? One scenario consistent with such an explanation would be a dominant firm buying up innovative competitors and deliberately shutting them down in order to continue its own dominance (Rey & Tirole, 2006). However, this explanation is unlikely in our case, for if it were true, the acquired inventors would be expected to stop innovating completely after the acquisition. Instead, they continued to innovate but at a lower rate (Figures 1a and 1b). Furthermore, such tactics are usually used in highly monopolistic industries, whereas the semiconductor industry includes many participants and competition is intense. A second strategic possibility is that serial entrepreneurs sell out and then hire back the star inventors to join them in forming another new organization, leaving the acquiring firm with the less productive inventors. But this explanation is inconsistent with our data showing relatively low turnover among the inventors with high performance (Table 7).

Overall, we believe that though endogeneity remains a possibility, it is difficult to construct a credible alternative explanation that is consistent with our data. For example, such an explanation would have to account for the convergence of inventors from both acquiring and acquired firms to a similar (and nonzero) productivity level three to five years following the acquisitions (Figure 1b). It is more likely that firms do use acquisitions in the semiconductor industry as a mechanism for gaining new technological competences (Griffin, 1989; Vanhaverbeke et al., 2002). In press releases that we collected covering almost all the firms in our sample as well as in our field interviews, executives from acquiring firms emphasized the value of the acquired firms' technology and knowledge resources as a key source of value from acquisitions.

Our article makes several contributions to the literature. Firstly, it links the knowledge and incentive-based perspectives. We show that acquisitions are associated with a loss in the productivity of acquired inventors. However, the underlying mechanisms posited in the two perspectives differ. Incentive-based arguments are useful for under-

[11] It might also be argued that an acquiring firm will find it harder to retain employees from young start-up firms. However, we found that in the case of start-up firms less than seven years old, 15 percent of productive inventors left acquiring firms, compared to 14 percent from non-start-up firms. Hence, the difference was insignificant.

standing the impact of structural changes on inventor incentives (e.g., firm size, make versus buy decisions), but the knowledge-based perspective is useful for understanding the coordination and learning processes within organizations.

Our article also illustrates how incentive-based and knowledge-based perspectives are not just complementary, but deeply intertwined. They are not just different sides of the same coin, but the two lenses on a pair of spectacles. The research agenda of scholars from each side should be adapted to synthesize the essential elements from the other side. A knowledge-based theory of the firm is incomplete if it only emphasizes coordination and learning while neglecting incentives. An incentive-based model may be elegant, but it needs to include the contextual and socially embedded nature of knowledge to be useful.

We also make several empirical contributions. By using analysis at the level of individuals (inventors), we were able to explore the microfoundations of earlier firm-level studies. The decline in postacquisition patenting observed by Hitt et al. (1991) is in line with our finding of a decline in patenting at the individual level. However, we go beyond those studies to show that the degree to which acquiring and acquired firms have overlapping knowledge (Ahuja & Katila, 2001; Lane & Lubatkin, 1998) and relative size condition the effect even after controlling for postacquisition integration and the preacquisition productivity of inventors. We also hope that results in Table 7 will motivate managers and scholars to move beyond employee retention as a key issue to explore how to make the retained workers more productive.

Finally, our findings contribute to the literature on knowledge spillovers. We suggest that scholars have to reintroduce incentives and productivity into the discussion of strategies used by firms to access external knowledge (e.g., by acquiring intellectual property, geographical colocation, hiring talented individuals, and alliances). In addition, there is a need to consider social welfare implications. Hoetker and Agarwal (2007), who examined how firm exit impacts innovation (but not exit via acquisitions) also expressed this concern. They showed that when firms exit an industry, private knowledge, which is often tacit and socially embedded, is lost, and this loss may have negative welfare implications. This concern raises the question of whether the fall in inventor productivity accompanying an acquisition might adversely affect other firms producing complementary innovations.

Several limitations of our study point to potential research opportunities. Our sample is restricted to a single industrial context, and there is a need to conduct similar studies in other industries, such as pharmaceuticals and computer networking, where acquisitions are an important instrument for accessing new technologies. The development of a research design to evaluate different levels of integration would be another fruitful extension of our research. Another issue concerns the inability of patent data to identify inventors who moved into management or other roles within their firms after acquisition, as well as those who left the acquired firms and did not patent from then on. Although the ZINB specification partially accounts for these possibilities, it would be preferable in the future to trace the actual exit of inventors, as Mayer and Kenney (2004) did. Finally, we have taken utmost care in defining the matched-pair design, but several imperfections may remain. Future research could explore alternative methodologies for defining reference groups for the control sample and better matching algorithms. Despite these limitations, we believe our paper sheds new light on how the incentives-based and knowledge-based view complement each other, and we hope it places the integration of both perspectives high on the research agendas of scholars.

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APPENDIX

Hypothesis 2b: A Short-Term Test

We modeled the postacquisition productivity of an inventor (Y) as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \mathrm{u},$$

where X_1 is an inventor's preacquisition productivity, X_2 is a measure of the inventor's career life cycle (Levin & Stephan, 1991), X_3 is the inventor's area of technical specialization, X_4 is a measure of disruption after the acquisition, X_5 is the strength of incentives in the acquiring firm, and u is an error term.

The postacquisition productivity of acquired inventors differs from that of matched inventors from their acquiring firm by the following amount:

$$Y_{\text{acquired}} - Y_{\text{acquiring}} = \Delta Y_{\text{m}} = \beta_1 \Delta X_1 + \beta_2 \Delta X_2 + \beta_3 \Delta X_3 + \beta_4 \Delta X_4 + \beta_5 \Delta X_5 + \varepsilon.$$

Theoretical Arguments

The greater the disruption, the lower an inventor's postacquisition productivity (i.e., $\beta_4 < 0$).

Following acquisition of his or her firm, an employee faces greater disruption than does an employee from the acquiring firm (Capron, 1999; Schweiger & Walsh, 1990). Hence, immediately following the acquisition, we expect that $\Delta X_4 > 0$.

Upon acquisition, it is unlikely that firms can offer widely differing incentives for newly acquired employees and existing employees (Milgrom & Roberts, 1992). Hence, we expect that the acquired and acquiring employees face similar incentives in a given year after an acquisition, and that $\Delta X_5 \sim 0$.

Effect on Postacquisition Performance

Our matching algorithm ensures that:

(a) $\Delta X_2 \sim 0$, i.e., the acquiring and matched acquired inventor are at the same stage of their career life cycle (the procedure is described in the text, and statistical results reported in footnote 10).

(b) $\Delta X_3 \sim 0$, i.e., the acquiring and matched acquired inventor have the same technical specialization (per the same procedure noted in "a").

Hence, for a matched pair of inventors:

$$\Delta Y_{\text{m}} = \beta_1 \Delta X_1 + \beta_4 \Delta X_4 + \varepsilon.$$

Taking expectations:

$$E(\Delta Y_m | \Delta \boldsymbol{X}) = \beta_1 E(\Delta X_1) + \beta_4 . E(\Delta X_4). \qquad (1)$$

Case A: Perfect matching ($\Delta X_1 \sim 0$). Ideally, the matching process is able to identify the control group of inventors at the acquiring firm having the same preacquisition productivity as that of inventors at the acquired firm i.e., $\Delta X_1 \sim 0$. Therefore,

$$E(\Delta Y_{\text{m}} | \Delta \boldsymbol{X}) = \beta_4 E(\Delta X_4).$$

According to the theoretical arguments, $\beta_4 < 0$ and $\Delta X_4 > 0$. Hence, $E(\Delta Y_{\text{m}} | \Delta \boldsymbol{X}) < 0$, or $E(Y_{\text{acquired}}) < E(Y_{\text{acquiring}})$. Hence, with perfect matching, an acquired inventor should have lower postacquisition performance than the matched inventor from the acquiring firm. This result is driven by the degree to which the acquiring and acquired inventor face disruptions (ΔX_4). Thus, the performance difference should be significant immediately after acquisition but diminish as the disruption dissipates (Hypothesis 2b).

Case B: Imperfect matching ($\Delta X_1 \neq 0$). Our matching process was limited by sample availability. As shown in Table 3, in three of the five years prior to acquisition, acquired inventors had greater preacquisition productivity than the matched inventors from acquiring firms—i.e., $\Delta X_1 > 0$. In this case, Equation 1 suggests that postacquisition performance differences are driven not just by the difference in disruption (ΔX_4), but also by the difference in preacquisition productivity (ΔX_1).

Table 3 (lower half) shows that immediately following an acquisition, acquired inventors exhibit lower performance than the matched inventors: $E(\Delta Y_{\text{m}} | \Delta \boldsymbol{X}) < 0$. Furthermore, in lower Table 4 and in Table 6, higher preacquisition productivity leads to higher postacquisition productivity—i.e., $\beta_1 > 0$. As before, $\beta_4 < 0$.

Rearranging Equation 1,

$$E[\Delta X_4] = \underbrace{1/\beta_4}_{<0} \left(\underbrace{E[\Delta Y_m | \Delta \boldsymbol{X}]}_{<0} - \underbrace{\beta_1}_{>0} \underbrace{E[\Delta X_1]}_{>0} \right).$$

The expression in the large parentheses is negative; therefore, $E(\Delta X_4) > 0$.

Hence, even with imperfect matching, if the postacquisition productivity of acquired inventors is less than that of matched inventors from the acquiring firm, and if higher preacquisition productivity leads to higher postacquisition productivity, then the disruption to acquired inventors is greater than that to matched inventors at the acquiring firms. So, although imperfect matching prevents a direct test of Hypothesis 2b, we were still able to test its main assumption.

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