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Don't Fence Me In: Fragmented Markets for Technology and the Patent Acquisition Strategies of Firms

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How do firms avoid being "fenced in" by owners of patented technologies used, perhaps unknowingly, in the design or manufacture of their products? This paper examines the conditions under which firms expand their own portfolios of patents in response to potential hold-up problems in markets for technology. Combining insights from transactions cost theory with recent scholarship on intellectual property and its exchange, I predict firms will patent more aggressively than otherwise expected when markets for technology are highly fragmented (i.e., ownership rights to external technologies are widely distributed); this effect should be more pronounced for firms with large investments in technology-specific assets and under a strong legal appropriability regime. Although these characteristics of firms and their external environments have been highlighted in the theoretical literature, prior research has not explored the extent to which such factors *interact* to shape the patenting behavior of firms. To empirically test these hypotheses, I develop a citations-based "fragmentation index" and estimate the determinants of patenting for 67 U.S. semiconductor firms between 1980 and 1994. Accumulating exclusionary rights of their own may enable firms to safeguard their investments in new technologies while foregoing some of the costs and delays associated with ex ante contracting.

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1. Introduction

In their quest to develop and commercialize new technologies, firms draw upon their existing stocks of knowledge while searching for ways to integrate and improve upon outside discoveries (Kogut and Zander 1992, Helfat 1994). Recognizing that cumulative innovation is vital to both firm performance and economic growth, management scholars have examined a range of mechanisms that facilitate the transfer of technologies and know-how across organizational boundaries, including internal R&D programs (Cohen and Levinthal 1990) and alliances (Stuart 2000, Mowery et al. 1996) as well as participation in professional communities (Henderson and Cockburn 1994, Gittelman and Kogut 2003) and the hiring of employees (Almeida and Kogut 1999). While illuminating the formal and informal channels through which knowledge flows, this literature implicitly assumes that firms have legal rights to make, use, or sell technologies they internalize.

Although the challenges that firms face in assembling rights to outside technologies have received little attention to date in management studies of innovation and technology transfer, they are the subject of considerable debate within the economics, legal, and public policy communities. Igniting this debate is an unprecedented surge in patenting within the United States.[1] Record numbers of patents are being issued from the U.S. Patent and Trademark Office (USPTO) in areas ranging from semiconductors and software to Internet business methods and gene sequences, raising concerns about the costs and feasibility of navigating through overlapping claims in these areas. Meanwhile, legal disputes over intellectual property have become more frequent and costly to defend (Lanjouw and Schankerman 1997). One study, for example, suggests U.S. firms spent over $1 billion enforcing or defending against patent lawsuits filed in 1991 alone, an amount equal to almost one-third these firms' investments in basic research and development (R&D) that year (Lerner 1995). Some suggest that this increased acquisition and enforcement of patent rights is creating a problem in technology markets similar to that posed by an "overfencing" of land (David 2001): When licenses from too many

[1] More than 1.5 million patents have been granted in the United States since 1990, with almost 170,000 awarded in 2001 alone (based on calculations from U.S. Patent Statistics, available at www.uspto.gov). Jaffe (2000) and Gallini (2002) discuss these trends in more detail and review the related literature.

individual property owners are required, firms may underinvest in the commercialization of downstream technologies (Heller and Eisenberg 1998). Others raise similar concerns about the effects of dense "thickets" of overlapping patent claims, but predict that firms will "navigate" through these thickets by devising institutional solutions such as patent pools or joint ventures (Merges 2001, Shapiro 2001), or by acquiring firms with blocking patents (Graff et al. 2003).

This paper examines the conditions under which an aggressive patenting strategy is an alternative mechanism that firms use to avoid being "fenced in" by owners of technologies used, perhaps unknowingly, in the design and manufacture of their products. Combining insights from transactions cost theory with studies of intellectual property (IP) and its exchange, I predict firms will patent more aggressively than otherwise expected when rights to complementary patents (i.e., ones that would likely be infringed if the firm manufactures or sells its products without a license) are widely distributed among outside entities; this effect should be amplified for firms with large investments in technology-specific assets. The central argument is that firms commercializing technologies that draw upon a concentrated pool of outside inventions can safeguard their investments more effectively through use of ex ante mechanisms such as joint ventures or patent pools. In contrast, the costs and delays associated with ex ante contracting render such an approach infeasible for firms building on technologies held by a more disparate set of owners, increasing the strategic value of patenting for use in ex post licensing transactions. Laws governing the strength and enforceability of patents mediate these effects, as discussed below.

Identifying all technologies used in the development or manufacture of a firm's products is an arduous if not impossible task, even without linking those technologies to patents and their respective owners. In line with a growing number of economics and management studies (discussed in §3), I use linkages revealed in patent citations data to identify organizational "shoulders" on which a firm's inventions stand. More unique is my use and interpretation of these data. Relaxing the implicit assumption that knowledge flows freely across organizational borders, I use patent citations to identify a list of potential licensors and estimate whether the rights to a firm's complementary patents are widely distributed or held by a few key players. In doing so, I construct a time-varying proxy (hereafter called the "fragmentation index") that captures this dimension of external technology markets that is prominent in the theoretical literature but previously unexamined in a large-scale empirical study. I test the effects of fragmented rights on incentives to patent using a sample of 67 U.S. semiconductor firms in periods that predate and follow reforms that effectively strengthened U.S. patent rights (Jaffe 2000).

Several contributions stem from this research. First, it deepens our understanding of the broader, strategic motives for patenting. Management scholars have long recognized that some firms accumulate portfolios of patents for trading purposes—either to gain more favorable access to outside technologies or to reduce the outflow of licensing fees (e.g., Von Hippel 1988, Westney 1993, Grindley and Teece 1997). Indeed, recent survey evidence suggests the *primary* reasons firms patent in complex industries such as electronics, semiconductors, and computing are (1) to prevent rivals from patenting related inventions (i.e., "patent blocking"), (2) to use in negotiations with owners of outside patents and technologies, and (3) to deter patent infringement lawsuits (Cohen et al. 2000). This paper builds on this literature, while suggesting these strategic uses of patents may vary considerably even within an industry and are driven by both firm-specific and environmental factors.

The paper also contributes new empirical evidence regarding the determinants of patenting in semiconductors, a sector characterized by a fluid, highly cumulative process of innovation. In an earlier study, Bronwyn Hall and I found that the "propatent" shift in U.S. policies during the 1980s stimulated entry by specialized firms into the industry while inducing "patent portfolio races" among firms with large, complex manufacturing facilities (Hall and Ziedonis 2001). Our interviews with executives suggested the latter "racing" effect was driven not only by the (observable) scale of their investments but also by the (unobservable) likelihood of ex post licensing negotiations with outside patent owners. Drawing on these qualitative insights, this paper develops the theoretical arguments more fully and devises a way to disentangle these two effects. The results suggest the "portfolio racing" observed in Hall and Ziedonis (2001) was *not* driven by firm-level investments alone, but—as predicted—by the subset of capital-intensive firms drawing upon a fragmented pool of external technologies. Also in line with theoretical predictions, the results show that these effects become more pronounced under the strengthened legal appropriability regime.

Finally, the paper contributes to the emerging literature on hold-up problems in markets for technology and their implications for firm strategy (Arora et al. 2001). More specifically, I explore trade-offs among mechanisms widely discussed in the prior literature (e.g., redirecting or curtailing R&D programs or forming patent pools) and identify conditions under which an aggressive patent acquisition strategy represents an alternative organizational response. The results suggest that interactions between the internal characteristics of firms and their environments affect not only the expropriation risks posed by outside patent owners but also how firms choose to safeguard their investments in light of those risks. In §2, I discuss hold-up problems in the markets for patented technologies, draw parallels with the traditional transactions cost literature, and develop three main hypotheses. Section 3 introduces the fragmentation index, while §4 describes the empirical setting, key variables, and econometric methods. Section 5 presents the results and explores alternative explanations. Conclusions follow.

2. Theory Development and Hypotheses

A lively theoretical debate has emerged over whether strengthening patent rights promotes or hinders the cumulative innovation process. On one hand, the optimal patent design literature in economics emphasizes the importance of allocating strong patent rights to the first inventor in the cumulative chain to induce sufficient levels of R&D investments (e.g., Scotchmer 1991). In contrast, other economists and legal scholars (e.g., Merges and Nelson 1990) challenge these prescriptions and highlight the difficulties inherent in IP-related transactions: patents are inherently difficult to value, their boundaries are blurry and difficult to demarcate, and parties in the "cumulative chain of innovation" are often unknown in advance, which further restricts the range of ex ante solutions. Recent theoretical attention has focused on two dimensions of a firm's contracting problem in markets for technologies: (1) the costs associated with being "held up" after improving upon or embedding technologies patented by others; and (2) the additional problems posed by multiple, fragmentary patent owners (i.e., the "patent thicket" or, more precisely, the "diffuse entitlements" problem). I now discuss these dimensions and how they interact to shape the patent acquisition strategies of firms.

2.1. Hold-up in Markets for Technology

The "hold-up" problem posed by outside patent owners is similar to the one long featured in the transactions cost literature (e.g., Williamson 1985, Klein et al. 1978). Simply put, hold-up occurs when one party is able to expropriate rents from another. A fundamental insight from transactions cost economics is that simple market contracts do not adequately safeguard against expropriation when investments in specific assets are involved, that is, when the assets cannot be redeployed to the next best use or user without significant loss of value (Klein et al. 1978). Transactions cost theory predicts firms will either (a) internalize transactions involving highly specific assets (i.e., "make" instead of "buy"), or (b) underinvest in areas where risks of expropriation are high (Williamson 1985).

The public-goods nature of intellectual property and the uncertainty and costs associated with demarcating property boundaries add an important twist to this traditional hold-up problem. A patent, if valid, grants a patentee the right to *exclude* others from use of the patented invention for a limited period; it does not grant the patent owner the right to *use* the patented invention if such use infringes on the rights of others. That is, it is an exclusionary right, not an affirmative right. If a firm independently makes an invention and uses it to improve the quality of its products or production methods, the firm does not necessarily own the rights to "practice" or use its invention if doing so infringes on the patent rights of others. Depending on the extent to which simultaneous use and duplicative inventions are likely to occur, a firm may therefore face a make-*and*-buy rather than a make-*or*-buy decision in these markets for technology. Attention then shifts to the price a firm expects to pay in the event it needs to purchase legal rights to use technologies patented by others, and ways to improve its ex post bargaining position.

In theory, a firm could simply invent around technologies owned by others and alleviate potential hold-up. Here, assumptions about the timing of investments and the feasibility and costs of ex ante contracting are critical. Consider, for example, the problem from the view of a semiconductor manufacturer. Suppose the firm could easily invent around an existing patent during the initial stages of designing new products or specifying the layout of new fabrication facilities. In this case, the royalties the patentee could obtain from the firm would necessarily be limited, ex ante, by the manufacturer's ability to invent around the invention (Levin et al. 1987, Teece 1986). The manufacturer would be in a far weaker negotiating position, however, if it learns about the patent *after* embedding the technology in designs or processes that are costly or difficult to redeploy. At this point, the invention represents a highly specific asset (in the classic transactions cost sense) even though the identity of the asset holder was unknown prior to the investment decision.

To illustrate the point, consider Intel's dilemma in 1998 when launching its first generation of 64-bit microprocessors, the Merced chip. After developing the architecture and tailoring its fabrication facilities to produce the new chip, Intel was sued by a small communications company, S3, for allegedly infringing patents S3 had purchased from a failed start-up company. One report aptly summarizes Intel's position:

> While analysts say it is not usually a problem to work around a patent of this type, Intel is so far down the path of designing Merced it would be very difficult to

> go back and change it now. And a possible court battle with S3 could delay the chip's introduction and conceivably lead to an injunction, preventing it from being shipped. This would leave the chip giant little option but to reach an agreement with S3 (*Global Newswire* 1998, p. 1).

Within months, Intel settled on undisclosed terms viewed as highly favorable to S3 in exchange for rights to use the patented technologies in its 64-bit products. Practitioner articles on the strategic management of patents are replete with similar examples of "minefield" patents, so called because they explode upon firms late in the development or adoption of a new technology (e.g., see Rivette and Klein 2000).

While the transactions cost literature highlights how the redeployability of a firm's assets might affect its risk of expropriation, a more recent line of research in the property rights tradition (Demsetz 1967, Libecap 1989) emphasizes how the external allocation of property rights affects the feasibility of devising ex ante solutions (e.g., Heller 1998, 1999; Heller and Eisenberg 1998).[2] The underlying idea is that granting too many individual exclusionary rights (of too small a scale) can prevent economic resources from being effectively exploited. As a result, the resource may be underutilized.

A subtle but important insight from this "anticommons" (or "diffuse entitlements") theory is that a firm's bargaining challenge is affected by the level of *dispersion* among rights holders—not just by the number of patents in a "thicket" or the number of owners per se (as modeled by Shapiro 2001 and Buchanan and Yoon 2002). This insight is especially powerful in the context of poorly defined assets such as intellectual property. As noted earlier, the degree to which one patent's claims infringe upon those of others is both difficult and costly to ascertain (Merges and Nelson 1990). Moreover, the economic value of intellectual property is highly context specific, hinging on its use within a particular technological or competitive setting (Teece 1986). These characteristics of patent rights and the process of their exchange suggest that IP-related bargaining costs depend critically on how external rights are distributed.

To clarify the point, consider a hypothetical example of a semiconductor manufacturer deciding to invest $1 billion in a new fabrication facility (fab). Assume the firm has identified 1,000 patents it believes *might* be infringed on in the design or manufacture of its products. At this point, however, the firm is still unsure whether these patents are valid and, if so, the effective scope of their claims. Should the firm negotiate rights to use these technologies with their respective patent owners prior to building the facility? Examine the trade-offs posed by two extreme scenarios. Under Scenario 1, assume the 1,000 patents are all assigned to one firm. Under Scenario 2, assume the patents are assigned to 1,000 different entities. In a Coasian setting of zero transactions costs, of course, firms could engage in efficiency-enhancing trades regardless of how the initial entitlements are distributed (Coase 1960). Once we assume nontrivial transactions costs, however, differences in the bargaining costs under the two scenarios may influence how the firm responds to the expropriation risks posed by outside patent owners.

Under Scenario 1, it is reasonable to expect the manufacturer to either (1) contact the patent owner to secure a license or an alternative contractual arrangement (e.g., an alliance, joint venture, or acquisition) *before* investing in the facility, or (2) choose to invent around the patents (if possible). The firm also could proceed without permission from the patentee. In this case, however, its concentrated use of one owner's technologies would increase the probability that acts of infringement would be detected. Finally, if the firm contacts the patentee and she is willing to negotiate a license, they could reduce the per-patent cost of valuing the rights by restricting attention to the most valuable inventions. Grindley and Teece (1997) suggest that electronics firms use lists of "proud patents" in cross-licensing negotiations in precisely this manner: Royalty payments are based on valuations of a subset of the entire portfolio.

In contrast, the costs and potential delays involved in bargaining with the myriad, fragmented rights holders under Scenario 2 may render a reliance on ex ante solutions infeasible for the manufacturer. The firm could again seek a right to use the patented technologies from each owner before investing in or building on the respective inventions. Before doing so, however, the firm would want to examine more carefully whether, in fact, each patent is valid and, if the patent is likely to be valid, whether the claims "read on" (or cover) the manufacturer's products or use of the invention. The firm would also estimate the probability that each patent owner would exclude the firm from use of the invention ex post or seek payments in exchange for such use. Finally, and in contrast to Scenario 1, the firm is unable to spread

[2] Michael Heller introduced the so called "tragedy of the anticommons" to explain the underutilization of retail stores in postcommunist Russia due to multiple agents with partial but exclusionary rights to the property (Heller 1998, 1999). Heller and Eisenberg (1998) extend the theory in a critique of patents on genetic sequences and receptors used to screen drug targets, cautioning that the proliferation of patents in the field could stifle the development of downstream products. Argyres and Liebeskind (1998) raise similar concerns about the privatization of the "intellectual commons," but focus on how the allocation of patent rights to university inventions could affect academic research, including its dissemination and use.

the valuation costs across individual owners given the idiosyncratic and context-specific nature of the asset. This discussion does *not* suggest the manufacturer will forego ex ante agreements under Scenario 2 and secure them under Scenario 1. Rather, it suggests this distributional characteristic of the firm's external market for technology has important implications for the costs and potential delays associated with ex ante solutions.

2.2. Implications for Patent Acquisition Strategies

The above discussion highlights two key factors (one internal, one external) that affect a firm's risk of patent-related expropriation and the feasibility of mitigating those risks through ex ante contracting: Expropriation risks are higher for firms with assets that are costly to redeploy to alternative uses or users (in line with traditional transactions cost reasoning); ex ante contractual solutions are more costly (less feasible) for firms that draw on fragmented pools of external technologies.

The current debate in the theoretical literature tends to focus on whether these contractual dilemmas will lead firms to underinvest in innovation (a central hypothesis in anticommons theory) or whether institutional solutions such as patent pools, cross-license agreements, or collective rights organizations will arise to bundle and reduce the collective transactions costs (as discussed above and in Merges and Nelson 1990, Merges 2001, and Shapiro 2001). The question also arises: If external patent rights pose a real risk of hold-up, why do not firms simply acquire (internalize) the owners of those patents? In some cases, this is a feasible strategy. Intel's 1998 acquisition of Digital Equipment's semiconductor facilities in the wake of a patent infringement suit and Mentor Graphic's unsuccessful bid to acquire Quickturn Design Systems are two examples. But mitigating expropriation risk through acquisition involves important direct and indirect costs of its own, including the direct costs of the acquisition and indirect costs associated with diminished flexibility and unrealized gains from trade with specialized firms, which is often critical in high-technology industries.

Another important mechanism firms use to mitigate hazards in markets for technology is to amass larger patent portfolios of their own in an attempt to improve their ex post bargaining positions. In effect, building a larger portfolio of patents is an attempt to create a de facto "exchange of hostage" (Williamson 1983). By increasing the likelihood the firm can threaten others with reciprocal suit, the firm may be able to avoid rent expropriation from patent owners or, at least, minimize its effects, as evidenced by the survey evidence of Cohen et al. (2000) and in interviews by Hall and Ziedonis (2001). The incentives for firms to patent aggressively thus in part depend on the value they place on improving their bargaining power in future rounds of licensing negotiations.

Two main hypotheses follow from this and the earlier discussion. First, if fragmented rights to patents render ex ante contracting less feasible, we should expect firms that draw on widely distributed technologies to patent more aggressively (controlling for other determinants of patenting) than firms that face more concentrated external markets for technology.

Hypothesis 1. *The more fragmented the external technology markets, the more aggressively firms will patent (beyond what is otherwise predicted).*

Furthermore, as suggested earlier, an aggressive patent acquisition strategy should be particularly important when (a) external technology markets are highly fragmented *and* (b) the anticipated cost associated with being "held up" is large. Under such conditions, firms may invest more heavily in patents to forego the potential costs and delays of negotiating with diffuse patent owners while attempting to safeguard their investments from expropriation in line with arguments put forth in the preceding section.

Within the semiconductor industry, there are several reasons to assume that the business risks associated with patent-related expropriation are higher for firms with large sunk investments in manufacturing facilities. Semiconductor manufacturing is notoriously complex, integrating an array of process and product technologies that cover aspects of the circuitry design, materials used to achieve a certain outcome, and methods used in the wafer fabrication process (Grindley and Teece 1997). The design, layout, and processes used in state-of-the-art facilities are highly interrelated and are tailored for particular generations and types of products. Moreover, investment decisions must be made years prior to the launch of a new product—a period in which many patents could issue.

In addition to representing highly "specific" assets (in the transactions cost sense), state-of-the-art facilities also are expensive to build and depreciate rapidly. As reported in Hall and Ziedonis (2001), a state-of-the-art wafer fabrication facility in the early 1980s cost about $100 million and had an expected life span of 10 years. By the mid-1990s, the cost had risen to over $1 billion for a new fab, while the useful life of the capital investment had been reduced to little more than 5 years. As one patent manager we interviewed noted, "A preliminary injunction would be detrimental to a firm if it means shutting down a high-volume manufacturing facility; loss of one week's production alone can cost millions of dollars." The larger the firm's sunk investments in such facilities, the wider the range of agreements favoring the patent owner the firm would accept short of halting production. This generates a second testable hypothesis in the context of this industry:

Hypothesis 2. *The effect of fragmented external rights on incentives to patent will be more pronounced among capital-intensive firms* (*all else equal*).

Finally, both effects should be mediated by the laws governing the strength and enforceability of patent rights. As mentioned earlier, important changes in the U.S. legal environment during the 1980s effectively strengthened the rights of patent owners in the United States.[3] Notable among these reforms was the 1982 creation of the Court of Appeals for the Federal Circuit (CAFC). As a centralized appellate court for federal patent cases, the CAFC is widely credited with tilting the judicial treatment of patent rights in the United States more in favor of the patentee and helping transform the U.S. legal environment from one that was generally skeptical of patents to one that promoted the broad, exclusive rights of patent owners. For example, the new court expanded the potential boundaries of patent owners' claims through its interpretation of scope and made it more difficult to challenge a patent's validity by raising evidentiary standards (Jaffe 2000). The court was also more willing to grant preliminary injunctions to patentees during infringement suits (Lanjouw and Lerner 1996), sustain large damage awards and thereby increase the penalties associated with acts of infringement (Kortum and Lerner 1998), and issue rulings that have been collectively construed as "propatent" (Jaffe 2000, Galini 2001). Plaintiff success rates in patent infringement suits also increased substantially during this period (Lerner 1995).

Recognizing this external shift in the legal environment could affect both the economic incentives of patent owners to enforce their rights and the incentives of firms to avoid being "held up," the final hypotheses predict that the impact of disperse outside patent rights on the patenting behavior of firms will be amplified under the strengthened legal enforcement regime:

Hypothesis 3a. *The effect of fragmented external rights on incentives to patent will be stronger following the "propatent" shift in the U.S. legal environment* (*all else equal*).

[3] My discussion of these changes and their perceived effects is necessarily brief. Jaffe (2000) and Gallini (2001) provide more nuanced and extensive discussions. To avoid confusion, however, it is important to point out that the changes did *not* "strengthen" U.S. patents in the sense of awarding patents more selectively. In fact, Quillen and Webster (2001) find that the USPTO has screened out a remarkably low percentage of patent applications since the early 1980s (as little as 5%–10%).

Hypothesis 3b. *The interaction effect between fragmented rights and capital-intensity will be greater in magnitude following the "propatent" shift in the U.S. legal environment* (*all else equal*).

3. Constructing a Citations-Based Measure of Fragmented Markets for Technology

Despite considerable attention paid to the dilemmas of fragmented rights and IP-related hold-up in the theoretical literature, empirical scrutiny of these issues has been limited by a lack of reliable measures. An ideal measure would characterize the technologies used or built on by a firm and identify entities positioned to exclude the firm from use of those technologies. Unfortunately, a direct measure of a firm's technological inputs is not, to my knowledge, publicly available—certainly not in a form that would match technologies to patents and their respective owners. In theory, one could obtain subjective estimates from executives or R&D managers within firms. In a rapidly changing setting like semiconductors, however, it is unlikely such an approach would yield reliable indicators even if respondents were willing to disclose the information.

This paper overcomes some of these limitations by relying on indirect evidence contained in patent citations. When a patent is granted, an extensive public document is created that lists detailed information regarding the invention, the inventor(s), and the entity (or, less commonly, entities) to which the patent right is assigned. The front page of the published patent document also lists "citations," or "references," to previous patents and other nonpatented discoveries the invention has advanced upon, revealing technological linkages across generations of inventions (Jaffe and Trajtenberg 2002).

To estimate whether ownership rights to a firm's complementary patents are widely distributed, I construct a "fragmentation index" as follows:

$$\mathrm{FRAG}_i = 1 - \sum_{j=1}^{J}\left(\frac{\mathrm{NBCITES}_{ij}}{\mathrm{NBCITES}_i}\right)^2, \qquad i \neq j,$$

where j refers to each unique entity that is cited by patents issued to firm i (i.e., the number of backward citations, or NBCITES) in a given year. For simplicity, time subscripts are omitted. References to a firm's own patents, nonpatented materials, and expired patents are excluded from the measure since they pose no hold-up hazard. Finally, I adjust the index as recommended by Hall (2002), who shows that Herfindahl-based measures using patent data will be biased downward for firms with few patents. To correct for this statistical bias and assuage concerns that the index is simply functioning as a lagged indicator of patenting, I normalize the index as follows:

$$\hat{F}_i = \left(\frac{\text{NBCITES}_i}{\text{NBCITES}_{i-1}}\right)\text{FRAG}_i,$$

where NBCITES_i is the total number of citations listed in patents assigned to each firm (on an annual basis).[4] All reported results are based on this adjusted measure.

To illustrate how the index is constructed, consider the following stylized example. Assume that two firms, Firm A and Firm B, each receive 10 patents from the U.S. Patent and Trademarks Office in 1990 and that each firm's 10 patents collectively cite 100 other U.S. patents. Assume further that all of the 100 patents cited by Firm A are assigned to a single entity (for example, IBM). In this case, Firm A's fragmentation index for 1990 would equal zero (all cited patents are held by one entity and the index is at its minimum value). In contrast, assume Firm B cites patents that are assigned to 100 different entities (e.g., 1 to IBM, 1 to Texas Instruments, 1 to an independent inventor, etc.). Here, the legal rights to potentially exclude Firm B are widely dispersed across entities, as reflected in a fragmentation index that approaches one—the maximum value.

Should we infer from this measure that Firm A infringes upon the patents of one firm while Firm B infringes upon the rights of 100 separate entities? No. Recall that the objective of the measure is to distinguish—broadly—between firms for which the anticipated costs and delays associated with ex ante contracting may render such an approach infeasible and those for which ex ante contracting is a more viable strategy. Thus, we would infer from the above example that Firm A is *more likely* than Firm B to engage in negotiations with potential rights holders (in this case, IBM) to secure rights to patented technologies before building upon them further. Similarly, we would infer that ex ante contracting is *less* feasible for Firm B given the potential costs and delays involved in bargaining with the fragmentary owners (as suggested by anticommons theory). In turn, we predict that, all else equal, Firm B will devote more of its resources toward improving its bargaining position ex post (by acquiring more patents) than will Firm A.

Before drawing inferences from this citations-based measure, it is important to establish that: (1) citations identify technologies used or improved upon by firms, and (2) owners of cited patents are reasonable proxies for potential licensors (i.e., owners of complementary patents). In both instances, the citations-based measure provides a useful but imperfect proxy. The first point—that citations reveal some of the technological antecedents of a patent—has received considerable attention in a large and growing number of studies that utilize patent citations data to trace knowledge "flows" and "spillovers" across organizations, technologies, and geographic distances.[5] Although recognizing that citation-based measures are noisy indicators of technological linkages, these studies generally validate their use in identifying the technologies upon which other innovations build (Jaffe and Trajtenberg 2002).

Establishing the second point—that owners of cited patents are entities with whom the firm may need to engage in patent-related negotiations—requires a more significant departure from prior studies. A common inference drawn from citations-based studies is that patent citations measure the degree to which research undertaken by one entity spills over, or diffuses, to other firms or inventors, much like citations in an academic article suggest the author advanced upon the ideas or findings of others. Unlike article citations, however, the act of citation in the context of patents does *not* necessarily imply a costless exchange, as should be clear from the prior discussion. Thus, to continue the earlier example, if Firm A's patents build upon technologies invented by IBM, Firm A does *not* own a right to use the technology covered by its patents if doing so infringes upon the patent rights of IBM. This discussion suggests citations contained in patents, while potentially representing knowledge flows from one entity to another, also identify a set of entities with which a firm *may* need to engage in patent license negotiations.[6] The eventual outcomes of these negotiations, if any, will determine the magnitude of "balancing payments" from one party to another (Grindley and Teece 1997). A costless exchange is by no means assured.

Even though this citation-based measure enables me to identify a pool of potential licensors specific

[4] The resulting index is similar in spirit to one used by political scientists to measure the dispersion of legislators among political parties. For example, Rae and Taylor (1970) use a computationally equivalent measure to show that increased "fractionalization" within legislatures delays the speed with which agreement is reached over policy initiatives.

[5] Jaffe and Trajtenberg (2002) discuss these studies and the uses and interpretation of patent citations data.

[6] Anecdotal evidence suggests that some firms are using so called "citation maps" in precisely this manner. For example, Mogee Associates, a patent strategy consulting firm, reports "A major electronics manufacturer with a large patent portfolio was mounting an effort to license out or drop many of its patents and wanted a cost-effective way to screen patents for licensing value. We screened more than 700 U.S. patents . . . and generated lists of companies that cited the patents heavily . . . . This information was used to select the patents on which to concentrate licensing efforts and to identify possible licensees" (www.mogee.com 2003). Other IP consulting firms, such as InteCap and Delphion, market similar services.

to each firm, it has several inherent limitations. It is well known that patent citations are observed only when firms have chosen to patent their inventions and were successful at doing so. A firm also may cite another patent but not be required to license the earlier invention. For example, the owner may never seek to enforce the patent, the cited patent may not be infringed, or the cited patent may not be valid even if it is infringed. Moreover, a firm may engage in IP-related negotiations with patent owners (e.g., in joint development projects or in response to unanticipated threats of infringement suits), but never cite those inventions in its own patents. Thus, both "Type 1" (citation is observed but there is no risk of infringement/no need to license) and "Type 2" (there is risk of infringement/potential need to license but citation is not observed) errors undoubtedly exist. There is little reason to believe, however, that these errors bias the measure in ways that favor particular types of firms (e.g., by degree of capital-intensity) or years within the sample (e.g., during the propatent regime). As such, these imperfections in the measure should not vitiate the general purpose to which it is being applied.

4. Methodology

In the empirical analysis to follow, my goal is to use the fragmentation index to examine (a) the effect of fragmented external rights on incentives to patent (Hypothesis 1), (b) whether this effect is more pronounced among capital-intensive firms (Hypothesis 2), and (c) whether these factors play a more powerful role in predicting firm-level patenting under the strengthened legal appropriability regime (Hypotheses 3a and 3b). When testing for these effects, it is important to identify levels of patenting beyond what is otherwise predicted. To establish a reasonable baseline estimate, I use a "patent production function" developed by Pakes and Griliches (1980) and previously applied to the semiconductor industry by Hall and Ziedonis (2001). The sample, measures, and methods are summarized below.

4.1. Sample Selection and Data

Several characteristics of the semiconductor industry make it a useful empirical setting for this study. First, the semiconductor industry has a unique combination of capital- and research-intensity that, combined with short product life cycles, magnifies investment risks for firms.[7] Second, innovation in the industry is highly cumulative, with new products building on a large stock of prior inventions, made both internally and by others (Grindley and Teece 1997, Shapiro 2001). As discussed earlier, interview and survey evidence suggests these characteristics of firms within the industry alter their incentives to patent (Hall and Ziedonis 2001, Cohen et al. 2000), propositions this study seeks to develop more fully. Finally, in contrast to settings such as computer software or business methods, large numbers of semiconductor-related patents existed *prior to* the U.S. legal reforms in the 1980s; between 1969 and 1981, for example, more than 20,000 semiconductor-related patents had been awarded in the United States (USPTO 1995). This enables me to examine the extent to which, if at all, these firms' patent acquisition strategies become more responsive to the distribution of external patent rights following the "propatent" shift in the United States.

The sample of firms used in this study is based on a universe of 110 publicly traded U.S. firms whose principal line of business is in semiconductors and related devices (SIC3674) and that are included in Compustat between 1975 and 1996. Since corporate R&D spending is reported for a firm's entire portfolio of research activities, this approach enables me to obtain more precise estimates of the patent propensities of semiconductor firms during this 20-year period while keeping the broad technological area constant across firms. To assemble U.S. patents assigned to these firms, I identify name changes, subsidiaries, and merger and acquisition information from a variety of sources (including Lexis/Nexis business directories, 10-K filings, and the Directory of Corporate Affiliations) and retrieve information about those patents and the citations they contain using data from MicroPatent. I match these data with financial variables from Compustat, which I use to construct control variables such as R&D spending and size (discussed below). For all firms, financial data are converted to constant (1992) U.S. dollars to ensure comparability within the sample.

Eliminating duplicative observations and partially owned subsidiaries generates a sample of 72 firms in an unbalanced panel. These firms collectively received 14,365 U.S. patents between 1975 and 1996, which referenced 108,118 U.S. patents. Of these cited patents, 10,020 (9.3%) are assigned to the citing firm ("self-citations"). An additional 15,568 (14.3%) are to patents issued before 1975, a point at which assignee and inventor names are unavailable in electronic form. The remaining 82,350 citations (excluding pre-1975 cites and self-cites) were manually linked to more than 6,000 unique assignees or inventors and

[7] In 1996, for a group of leading U.S. producers with combined semiconductor sales of over $37 billion, semiconductor-specific capital expenditure amounted to more than 25% of sales, while R&D expenditures were nearly 12% of sales. Both figures outweigh corresponding data for leaders in industries such as chemicals, pharmaceuticals, aerospace, and autos (calculated from Compustat data).

used to calculate an annual fragmentation index for each firm in the sample.[8]

The estimation sample is based on observations during the 1980–1994 period, generating 667 observations on 67 firms.[9] As shown in Table 1, the median firm in the sample has 570 employees, spends $4.83 million (1992 dollars) on R&D, and successfully applies for one patent a year. The distribution of these variables is highly skewed, however, with one firm (Texas Instruments in 1994) applying successfully for 565 patents in one year and another spending over $1 billion in one year on R&D (Intel in 1994). The median value of the annual fragmentation index is 0.79, with a predictable range between 0 and 1. In 44% of the observations, however, a firm does not receive a patent in a given year, and the fragmentation index is reported as missing. As shown in Panel B of Table 1, omitting missing observations of the fragmentation index generates a sample of larger firms that spend more on R&D and obtain more patents. To avoid restricting the sample in ways that would favor the dependent variable (probability of patenting) and to retain important information regarding firms *unlikely* to patent, I include missing observations of the fragmentation index in the regression but treat them separately with a dummy variable (DFRAG). Estimates based on the restricted sample in Panel B only strengthen the main results, as shown below.

Table 1 Sample Statistics

Variable name	Mean	SD	Median	Min	Max
A: Sample used in estimation 667 observations (67 firms) 1980–1994					
Patent applications	17.56	58.88	1.00	0.00	565.00
R&D spending ($M 1992)	39.00	112.28	4.83	0.00	1,061.40
R&D intensity* ($M 1992 R&D/ 1,000 employ)	6.68	1.38	7.10	0.00	134.74
Employment (1,000s)*	0.64	1.76	0.57	0.02	89.88
Capital-intensity* ($M 1992 bk value PPE/1,000 employ)	27.11	0.80	28.50	0.84	165.64
Fragmentation index	0.52	0.37	0.79	0.00	1.00
D(FRAG = missing)	0.44	($N = 295$)			
D(R&D = 0 or missing)	0.07	($N = 44$)			
B: Restricted sample that omits missing observations of fragmentation index 372 observations (57 firms) 1980–1994					
Patent applications	31.45	76.06	6.00	0.00	565.00
R&D spending ($M 1992)	69.35	143.35	14.68	0.00	1,061.40
R&D intensity* ($M 1992 R&D/ 1,000 employ)	10.18	1.13	11.47	0.00	134.74
Employment (1,000s)*	1.44	1.71	1.25	0.00	89.90
Capital-intensity* ($M 1992 bk value PPE/1,000 employ)	37.89	0.68	37.38	3.12	165.60
Fragmentation index	0.89	0.11	0.92	0.00	1.00
D(R&D = 0 or missing)	0.01	($N = 2$)			

*Geometric means are shown for these variables, along with the standard deviation of the log.

4.2. Model Specification and Variables

To estimate each firm's propensity to patent, I follow the prior economics literature on patenting and R&D (e.g., Hausman et al. 1984) and specify the dependent variable as the number of successful patent applications made by a firm in a given year. Since patenting is a count variable that includes many zeroes and ones, I use Poisson-based models and estimation methods. As in Hausman et al. (1984), the expected number of patents applied for during the year is assumed to be an exponential function of the firm's R&D spending and other characteristics X_{it}:

$$\mathbf{E}[p_{it} \mid X_{it}] = \lambda_{it} = \exp(X_{it}\beta + \gamma_t),$$

where i indexes the firm and t indexes the year. γ_t is an overall year-specific mean that measures the average patenting across all firms, adjusting for the changing mix of firms in the sample. The data set is therefore a panel and the unit of analysis is a firm year. A Lagrange Multiplier (LM) test from Cameron and Trivedi (1986) rejected the pure Poisson model in favor of a model where the variance is proportional to the mean. To estimate the "patent production function," I therefore use a negative binomial specification, which is a generalization of the Poisson model commonly used under conditions of

[8] For patents assigned to sample firms, I coded backward citations based on entity-level portfolios. I then created a unique code for each major assignee or inventor name and combined patents assigned to obvious misspellings, permutations, or abbreviations of that name to each respective code. In the event the assignee field was blank, I retrieved the name of the first inventor on the patent and created a common code for each unique inventor name. To verify that my approach generated a reasonable set of semiconductor patent owners, I constructed a table of the most frequently cited entities in five-year intervals, which is available at http://mansci.pubs.informs.org/ecompanion.html. As shown in Table A.1 of the online appendix, the list includes both well-known sources of semiconductor technologies (such as IBM and AT&T) and large patent owners (like Texas Instruments and Japanese electronics firms). The overall share of citations represented by the top 25 entities was relatively stable across five-year intervals, despite considerable turnover among top-cited entities.

[9] Five firms with less than three years of valid data were removed from the sample. The time period was defined as 1980–1994 for several reasons. Prior to 1980, the truncation bias in the fragmentation index noted above was particularly pronounced. Annual time dummies mitigate the effects of this bias in the remaining years. Extending the series through 1994 enables me to estimate firm-level patenting for almost a decade following the demonstrated shift in the U.S. patent enforcement regime without rendering the manual coding of these data infeasible. Since the mid-1990s, patenting in this industry has continued to escalate; updating the data through 2000 would require the manual coding of more than 8,000 additional U.S. patents and 85,000 references (author's calculations). While adding precision to the estimates, extending the series would not contribute substantively to the central inquiry of this paper.

overdispersion.[10] "Robust" standard errors that correct for serial correlation and heteroskedasticity are reported throughout (Wooldridge 2002).

To establish a baseline estimate of each firm's propensity to patent, I first control for well-known determinants of patenting across industrial sectors and within the semiconductor industry in particular. Two key control variables from the prior literature include firm size (to allow for possible economies of scale in the patent application and prosecution process) and R&D spending (a critical measure of innovation inputs and an indirect proxy for technological opportunity). Following Hausman et al. (1984), I use contemporaneous levels of R&D spending in the specifications because of the high within-firm correlation of R&D spending over time and because many firms have short R&D histories. The base model also includes controls for known predictors of patenting within the semiconductor industry (Hall and Ziedonis 2001), including the book value of a firm's capital investments (a proxy for investments in technology-specific assets, as discussed earlier), and an indicator variable for Texas Instruments (TI), a firm with an unusually aggressive patent acquisition and enforcement strategy within the industry (Grindley and Teece 1997). To summarize, the baseline specification includes the following control variables:

• The *size* of the firm, measured as the logarithm of employment.

• *R&D spending* during the year in which the patent applications were filed (in $M 1992). To avoid confounding the R&D and size effects, R&D spending is normalized by number of employees to create an R&D intensity measure.[11] For the few observations where R&D is not reported, a dummy variable (DRND) is included so the R&D coefficient will not be biased.

• *Capital-intensity*, measured on an annual basis as the deflated book value of a firm's property, plant, and equipment, normalized by number of employees (consistent with Hall and Ziedonis 2001).

• A dummy variable for *Texas Instruments* (*TI*), an outlier within the sample.

• *Annual time dummies* for 1980–1994 to control for macroeconomic trends such as economic downturns and periods of technological ferment that could affect overall patenting levels.

To test Hypotheses 1 and 2, I augment the base specification by adding, sequentially, the following variables:

• A firm-specific annual *fragmentation* index (FRAG). As discussed earlier, a dummy variable (DFRAG) is set to one for missing observations of the index.

• An *interaction term* between the fragmentation index and capital-intensity (FRAG $*$ LnCapIntensity), as defined above.

Finally, to test Hypotheses 3a and 3b, I split the sample into years before and after the strengthened U.S. enforcement regime had been well demonstrated. Although the new appellate court was created in 1982, its significance was not widely felt until the mid-1980s (Jaffe 2000). Interviews with semiconductor executives suggest the large patent infringement suits won by Texas Instruments and Polaroid during 1985–1986 were particularly important "demonstration events" due to the large damages awarded and, in the Polaroid case, the closure of Kodak's manufacturing facilities (Hall and Ziedonis 2001). Echoing these views, a series of press reports appeared during 1985–1986, announcing "A Change in the Legal Climate" (*Forbes* 1985); "A Weapon at Last [propatent decisions]," (*Forbes* 1986); and "The Surprising New Power of Patents," (*Fortune* 1986). I therefore divide the sample into periods that predate and follow 1985, the latter of which corresponds to the era in which the "new power of patents" was widely known.

5. Results

Results are presented in Table 2 for the full sample period (1980–1994) and in Table 3 for the "before" and "after" subperiods. Column 1 in Table 2 presents baseline estimates with control variables and annual year dummies. Consistent with conventional wisdom, I find that larger firms and firms investing more heavily in R&D have a higher propensity to patent. The baseline model also corroborates findings from Hall and Ziedonis (2001): Capital-intensity is a strong, positive predictor of patenting among semiconductor firms (even controlling for the larger size and R&D programs of capital-intensive firms) and TI is an outlier within the industry. These effects are precisely estimated and persist in the more elaborately specified models.[12]

Turning to central variables of interest, Column 2 introduces the fragmentation index and Column 3 sequentially adds the multiplicative term. Including the fragmentation index in Column 2 substantially improves the overall fit of the model and significantly

[10] As discussed in Hall and Ziedonis (2001), one also can interpret the LM test as a diagnostic that indicates use of robust standard errors for the Poisson model, which will remain consistent, rather that implying a switch to a negative binomial model, which is potentially inconsistent. To increase confidence in the results, I ran each of the models using a Poisson specification and obtained similar results.

[11] Normalizing R&D spending by sales or assets did not alter the results.

[12] One exception is a lack of statistical significance of the R&D intensity coefficient in the conditional fixed-effects model (Column 8). This result is not surprising given the relative stability of within-firm R&D spending over time.

Table 2 Negative Binomial (NB) Estimates of Determinants of Patenting, 1980–1994 (67 U.S. Semiconductor Firms)

	Base model and main results			Robustness checks				
							Unobserved heterogeneity	
				Additional control tech opportunity	Restricted sample	Replace FRAG index with 3 yr. ma.		
Variable name	Base (Pooled NB) (1)	Add FRAG (Pooled NB) (2)	Full (Pooled NB) (3)	(Pooled NB) (4)	(Pooled NB) (5)	(Pooled NB) (6)	Random effects (Panel NB) (7)	Conditional fixed effects (Panel NB) (8)
Intercept	Year dummies	Year dummies	Year dummies	Year dummies	Year dummies	Year dummies	Year dummies	Year dummies
FRAG ∗ LnCapIntensity			1.848*** (0.464)	1.850*** (0.463)	5.025*** (1.642)	2.130*** (0.526)	1.135*** (0.360)	1.001** (0.403)
Fragmentation index		1.465** (0.673)	−4.401** (1.726)	−4.400** (1.728)	−13.833** (4.906)	−4.601** (1.543)	−3.034* (1.252)	−2.482 (1.426)
Dummy, missing FRAG		−2.666** (0.912)	−3.381*** (0.900)	−3.381*** (0.901)	—	−3.703*** (1.026)	−3.453*** (0.646)	−2.926*** (0.683)
Tech opportunity (Ln # impt. patents)	—	—	—	0.678** (0.245)	2.073** (0.733)	0.591*** (0.183)	0.533** (0.179)	0.572** (0.211)
Ln capital-intensity ($M 1992 PPE/empl)	0.505*** (0.153)	0.316*** (0.153)	−1.379*** (0.411)	−1.380*** (0.410)	−4.403** (1.662)	−1.563*** (0.428)	−0.968** (0.334)	−0.937** (0.378)
Dummy, Texas Instr.	0.827*** (0.239)	1.023*** (0.216)	1.074*** (0.237)	1.073*** (0.237)	1.096*** (0.252)	0.982*** (0.237)	3.333*** (0.634)	—
Dummy, missing R&D	−0.836 (1.025)	0.815 (0.669)	0.878 (0.644)	0.872 (0.643)	1.618* (0.624)	0.869 (0.612)	0.245 (0.762)	−0.206 (1.923)
Ln R&D intensity ($M 1992 R&D/empl)	0.493*** (0.106)	0.273*** (0.097)	0.286*** (0.087)	0.286*** (0.089)	0.297*** (0.086)	0.368*** (0.092)	0.245*** (0.067)	0.171 (0.099)
Ln firm size (1,000s employees)	0.905*** (0.060)	0.711*** (0.053)	0.705*** (0.052)	0.705*** (0.057)	0.698*** (0.062)	0.776*** (0.059)	0.412*** (0.054)	0.348*** (0.063)
δ (Variance parameter)	0.662 (0.111)	0.418 (0.065)	0.401 (0.059)	0.400 (0.058)	0.381 (0.148)	0.514 (0.079)	—	—
Log-likelihood	−1,438.8	−1,253.9	−1,242.6	−1,241.5	−1,193.1	−1,333.81	−1,219.4	−979.6
N	667	667	667	667	372	667	667	667
Chi-squared (*p*-value)		136.34 (0.000)	15.84 (0.000)	7.67 (0.005)	8.43 (0.001)	42.67 (0.000)	93.14 (0.000)	79.51 (0.000)

Notes. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

1. The method of estimation is maximum likelihood for the negative binomal model (generalized ML for the exponential mean function).
2. Heteroskedastic-consistent ("robust") standard errors are shown in parentheses.
3. The chi-squared is a Wald test versus the previous nested model in Columns 2–4 and versus the base model in Columns 5–8.
4. In Column 5, missing observations of the fragmentation index are omitted from the sample (see Table 1, Panel B).
5. In the conditional fixed-effects estimation (Column 8), 80 observations are dropped due to 9 firms that received zero patents over the sample period.

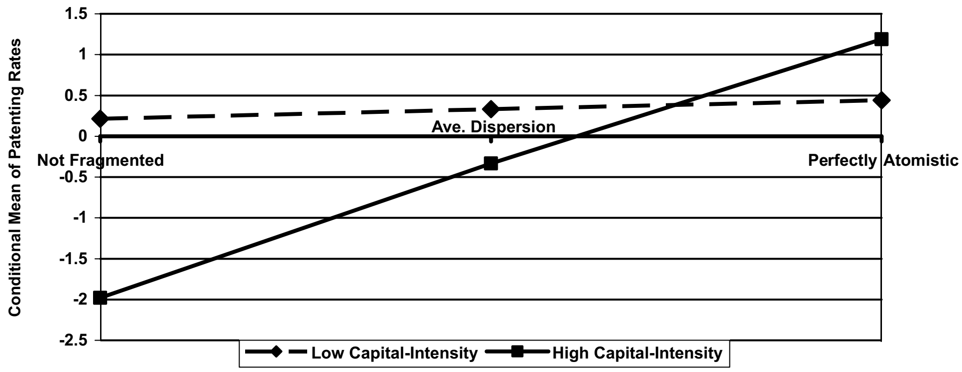
increases its explanatory power relative to the baseline model. The estimates in Column 3 also show the coefficient of the interaction term (FRAG ∗ LnCapInt) is positive and highly significant—as expected in Hypothesis 2. While the coefficients for the fragmentation and capital-intensity variables become negative in sign once the interaction term is included, computing the total slope of patenting with respect to fragmentation (holding all other variables constant at their conditional means) reveals the coefficients range in value from −4.72 (at the minimum value of LnCapInt, −0.175) to 5.04 (at the maximum value of LnCapInt, 5.11), with estimates of 1.70 and 3.16 at mean and one standard deviation above-mean levels of capital-intensity, respectively. Consistent with Hypothesis 1, the sign is positive across the entire sample range except for extreme outliers.[13] Based on these coefficients, the results suggest that capital-intensive firms (one standard deviation above the mean) will patent more than *five times* as aggressively in response to average levels of fragmented external rights as firms of average capital-intensity, even controlling for differences in R&D spending and size.[14]

Also interesting, the total slope coefficient for capital-intensity in Column 3 switches signs within

[13] More specifically, the sign is positive for values of LnCapInt ≥ 1.26, or 99% of the observed distribution. Table A.2 of the online appendix reports the conditional effect of fragmented rights on patenting at different levels of capital-intensity and the corresponding standard errors.

[14] That is, 22.57 ($= \exp(3.16) - 1$) is 5.05 times greater than 4.47 ($= \exp(1.70) - 1$).

Figure 1 Fragmented Rights, Capital-Intensity and Incentives to Patent



Notes.

1. Normalized to estimates of conditional effects at mean values of fragmentation and capital-intensity, all else constant.
2. "Low" and "High" values of capital-intensity defined at one standard deviation below/above the mean, respectively.
3. See Table A.2 of the online appendix for coefficient estimates and standard errors.

the sample and is positive only for above-mean values of fragmentation (at values ≥0.75). In other words, capital-intensive firms do not patent more intensively than other firms in the sample (again, controlling for other factors) *unless* they build on fragmented pools of outside technologies. This result, depicted graphically in Figure 1, provides indirect evidence in line with Hypothesis 2: Firms building on technologies owned by a more concentrated set of parties may rely more heavily on mechanisms other than patents (such as joint ventures, alliances, and other ex ante agreements) to safeguard investments that are difficult to redeploy ex post.

In Columns 4–8 of Table 2, I explore several competing explanations and analyze the sensitivity of these results. One competing explanation is that the fragmentation index is simply an indirect proxy for underlying shifts in technological opportunity (see discussion in Griliches 1990). For example, increases in technological opportunity could stimulate entry into the industry, leading more firms to patent while simultaneously boosting incentives to patent among incumbent firms. The specifications in Columns 1–3 already allow for this effect by controlling for R&D spending, which should rise with increases in technological opportunity, and annual year dummies, which allow average patenting rates within the sample to fluctuate over time. Nonetheless, I explore this issue by constructing an alternative, more direct measure of technological opportunities within the industry. Prior studies have controlled for technological opportunity using counts of U.S. patents in particular domains, adjusted by the number of subsequent citations to those inventions (see Jaffe and Trajtenberg 2002). Since citations-based measures using U.S. data would be endogenous to the types of strategic behavior of interest in this paper, I follow Cockburn and Henderson (1995) and construct a measure based on international patent filings. More specifically, I identify all semiconductor-related patents for which the applicant sought protection in each of the three largest markets for semiconductor products during 1980–1994: the United States, Germany, and Japan.[15] As shown in Column 4, this additional control for technological opportunity is indeed positive and statistically significant at the 1% level. I therefore include it in the remaining specifications. Column 4 also shows, however, that including this separate control for technological opportunity fails to alter the main results.

A separate competing explanation pertains to an omitted variable bias. I use the fragmentation index to infer potential hold-up problems in technology markets. An alternative interpretation of the same measure is that capital-intensive firms with (observable) high fragmentation indices also are engaged in a broader range of (unobservable) alliances or R&D agreements with other firms, universities, or research laboratories, which increases the efficiency of their R&D investments relative to other firms (Stuart 2000).[16] If true, we should expect the productivity of these firms' R&D spending to rise with increasing levels of fragmentation. In supplemental results, however, I found little evidence supportive of this view: Interacting R&D spending with the fragmentation index failed to produce a statistically significant coefficient (even at the 10% level) overall or for the subset of capital-intensive firms (at above-median values).[17] The results were also robust to the inclusion of

[15] I identify these patents using Derwent's technology groupings (category U) and World Patent Index, available at http://www. delphion.com.

[16] Increased "efficiency" in this context is defined as the generation of more patented output per R&D dollar, in line with economic studies of R&D productivity discussed in Griliches (1990).

[17] These and other supplemental results discussed below are shown in Table A.3 of the online appendix: http://mansci.pubs.informs.

interaction terms that allowed increases in technological opportunity to disproportionately boost the R&D productivity of capital-intensive firms.

The sensitivity of the results to alternative specifications and unobserved firm-specific effects are explored in Columns 5–8. The results in Column 5 establish that the results are not driven by the inclusion of missing observations of the fragmentation index. As expected, restricting the sample to firm-year observations with one or more successful patents only amplifies the magnitude of the effects. One might argue, however, that the degree of fragmentation in technology markets is a general characteristic of a firm's external environment and is better specified as a moving average. As shown in Column 6, similar results were obtained using three-year moving averages of the index instead.[18]

Another competing explanation is that some firms are simply "better" at assimilating external technologies from multiple sources and making efficient use of those inventions for reasons not accounted for by the independent variables. To allow for such additional sources of unobserved heterogeneity within the sample, I re-estimate the model using both random-effects and fixed-effects specifications for panel data.[19] As shown in Columns 7 and 8 of Table 2, however, the main results still hold. The size of the coefficient on the interaction term (FRAG ∗ LnCapIntensity) drops slightly, but is still significant at the 1% level or greater. The results also are robust to alternative sources of unobservable permanent fixed effects (using a "presample" instrumental variable approach) as well as unobserved time-varying effects (using lagged values of the dependent variable).[20]

In summary, these results suggest that the internal decision of firms to acquire patents is affected by the external distribution of patent rights surrounding their technologies. This finding is not explained by underlying shifts in technological opportunity, divergent R&D efficiencies, or unobservable sources of heterogeneity within the sample. The results lend qualified support for Hypothesis 1, but suggest the relationship between fragmented rights and incentives to patent is more complex than this hypothesis would suggest. Consistent with Hypothesis 2, the effect of fragmented external rights on incentives to patent in this industry is especially pronounced among capital-intensive firms.

Turning attention to Hypotheses 3a and 3b, I now examine whether the patenting behavior of semiconductor firms overall (and among capital-intensive firms) is more responsive to the distribution of outside patents after the "new power" of U.S. patents had been clearly demonstrated (i.e., after 1985). To ensure comparability, the estimation sample is restricted to 36 firms publicly traded before 1984 with two or more valid observations in each subperiod. Again, patent propensity estimates are generated using maximum likelihood methods, the negative binomial model, and "robust" standard errors.

For simplicity and in light of earlier findings, Table 3 presents results in Periods 1 and 2 using only the baseline and full models (corresponding to Columns 1 and 3 in Table 2, respectively). Comparing Column 1a and Column 2a replicates two main results from Hall and Ziedonis (2001): semiconductor firms' decision to patent became *less* responsive to changes in their R&D investments during the era of strong patent rights; and capital-intensity emerges as a strong, significant predictor of these firms' patenting behavior only under the "propatent" regime (supportive of the hypothesis that capital-intensive firms responded strategically to the legal reforms by amassing portfolios of patents).

The results in Columns 1b and 2b suggest, however, that the shift in patenting behavior was not driven by capital-intensive firms per se, but by the subset of capital-intensive firms that draw on technologies owned by a disparate set of outside parties.

org/ecompanion.html. As per one reviewer's suggestion, I also tested the sensitivity of the results to the inclusion of the dummy variable for Texas Instruments (TI). Column 2 in Table A.3 demonstrates that the main results hold even if the TI dummy is omitted, although doing so diminishes the overall predictive power of the model as would be expected given the statistical significance of this variable.

[18] Use of moving averages is vulnerable to the criticism that the measure is correlated with unobserved environmental variables, which could exaggerate the estimated effect. The coefficient on FRAG ∗ LnCapIntensity in Column 6 is indeed slightly larger in magnitude (2.130 versus 1.850) than the otherwise identical model in Column 4. I therefore report the more conservative results using point estimates.

[19] The random effects specification in Column 7 assumes that the unobserved firm-specific effects are uncorrelated with the independent variables. In contrast, the fixed-effects specification in Column 8 allows for unobserved permanent differences across firms (by conditioning on the total number of patents each firm receives during the sample period) but does not require these effects to be uncorrelated with the regressors. See Hausman et al. (1984) and Wooldridge (2002).

[20] These results are shown in Table A.3 of the online appendix (Columns 5–7). The "presample" approach, developed by Blundell et al. (1995), has been used in several recent studies of innovation rates in the strategy literature (e.g., Stuart 2000, Ahuja and Katila 2001). In line with recent studies, I construct the presample instrument based on the total number of patents a firm receives in the three years prior to entering the sample, which serves as an alternative "fixed effect" that partials out unobservable differences across firms. To account for any remaining serial correlation, I estimate the model using the Generalized Estimating Equations methodology (from Liang and Zeger 1986, discussed in Ahuja and Katila 2001) for both the Poisson and Negative Binomial specifications.

Table 3 Fragmented Rights and Incentives to Patent, "Before" and "After" Strengthened Enforcement Regime (36 Incumbent Firms, 1980–1985 vs. 1986–1994)

	Period 1: "Before" 1980–1985				Period 2: "After" 1986–1994			
Variable name	Base (1a)		Full (1b)		Base (2a)		Full (2b)	
Intercept	Year dummies		Year dummies		Year dummies		Year dummies	
FRAG ∗ LnCapIntensity			1.143*	(0.572)			2.138***	(0.618)
Fragmentation index			−3.125	(2.132)			−2.626	(2.752)
Dummy, missing FRAG			−4.849***	(1.208)			−1.061	(1.882)
Ln capital-intensity ($M 1992 PPE/empl)	0.116	(0.273)	−1.313**	(0.516)	0.540***	(0.193)	−1.444**	(0.547)
Dummy, Texas Instr.	1.036*	(0.342)	1.325***	(0.258)	0.739**	(0.282)	0.850**	(0.248)
Dummy, missing R&D	0.835	(0.936)	2.187***	(0.559)	−26.262***	(0.676)	−20.842***	(0.755)
Ln R&D intensity ($M 1992 R&D/empl)	0.554*	(0.237)	0.605***	(0.148)	0.377**	(0.124)	0.168	(0.109)
Ln firm size (1,000s employees)	0.867***	(0.089)	0.614***	(0.081)	0.919***	(0.077)	0.763***	(0.064)
δ (Variance parameter)	0.632	(0.278)	0.241	(0.087)	0.531	(0.099)	0.343	(0.064)
Log-likelihood	−327		−253.8		−843.9		−749.1	
N	185		185		362		362	
Chi-squared (p-value)			28.4	(0.000)			48.92	(0.000)

Notes. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
1. Sample includes firms publicly traded before 1984 with 2 or more valid observations in both periods.
2. The method of estimation is maximum likelihood for a negative binomial specification.
3. Heteroskedastic-consistent ("robust") standard errors are shown in parentheses.
4. The chi-squared is a Wald test (3 deg. freedom) comparing the unrestricted (B) and restricted (A) specifications.

Indeed, when rights to a firm's complementary patents are highly fragmented, capital-intensity is an even stronger positive predictor of patenting under the stronger enforcement regime than previously estimated. To see this, compare the 0.54 coefficient of capital-intensity in Column 2a with the larger total slope coefficient 0.69 (=2.138 − 1.444), implied by Column 2b when the fragmentation index is at its maximum value of 1. Moreover, the size of the coefficient on the interaction term (FRAG ∗ LnCapInt) is almost twice as large (2.138 versus 1.143) in Period 2 than Period 1, suggesting the combined effects of fragmented rights and capital-intensity play a larger role in shaping these firms' patenting behavior under the stronger legal enforcement regime. These results suggest the "patent portfolio races" identified by Hall and Ziedonis (2001) were not driven by capital-intensive firms per se, but by the subset of firms building upon fragmentary pools of external technologies. These results echo the qualitative findings from Hall and Ziedonis (2001) and are in line with the theoretical predictions of Hypotheses 3a and 3b. Previous empirical tests were not possible, however, without a way of disentangling the internal patenting decisions of firms from these characteristics of their external markets for technology.

6. Conclusions

Polanyi noted long ago that, "Invention, and particularly modern invention…is a drama enacted on a crowded stage" (Polanyi 1944, p. 71). Decades later, scholars continue to wrestle with the ever-vexing question: How do the rights of these myriad actors shape the drama of innovation that eventually unfolds?

This paper examines how the allocation of property rights among inventive actors shapes the patent acquisition strategies of firms. In doing so, it helps bridge a divide in the theoretical literature by (1) isolating two dimensions of a firm's contracting problem in markets for technology and (2) showing how firm-specific and environmental factors *interact* to shape incentives to patent. Consistent with predictions drawn from transactions cost and anticommons theories, I find that firms acquire patents more aggressively than otherwise predicted when markets for technological inputs are highly fragmented (i.e., when rights to a firm's complementary patents are widely distributed among outside parties). Moreover, this effect is noticeably more pronounced among firms with large investments in technology-specific assets and under a legal regime of strengthened exclusionary rights for patent owners. The specific estimates, based on a sample of 67 semiconductor firms during 1980–1994, suggest that capital-intensive firms patent more than *five times* as aggressively in response to average levels of fragmentation in markets for technology as firms of average capital-intensity, even controlling for differences in R&D spending and size. Moreover, and extending the earlier findings of Hall and Ziedonis (2001), I find that capital-intensive firms do not patent more intensively (again, controlling for other factors) *unless* they build on fragmented pools of outside technologies. There is little evidence to suggest that these findings are explained by underlying shifts in technological opportunity, divergent R&D efficiencies, or other unobservable sources of heterogeneity within the sample.

Several contributions stem from this research. First, the results suggest that the distribution of rights to proprietary technologies may not only shape the expropriation risks firms face in the manufacture or sale of their products, but also how firms choose to safeguard their investments in light of those risks. As discussed earlier, prior studies of patent-related hold-up have either assumed transactions costs away entirely or predicted more extreme outcomes such as an underutilization of new technologies or the formation of patent pools and other collective rights organizations. This study highlights the conditions under which firms amass portfolios of patents as an alternative organizational response. Accumulating exclusionary rights of their own may enable firms to safeguard their investments while foregoing some of the costs and delays associated with ex ante contracting. In effect, these intangible assets provide firms with a flexible set of "hostages" for use in ex post license negotiations much like equity ties and other formal provisions help firms mitigate expropriation risks in their collaborative ventures (as discussed in Oxley 1999). By increasing the likelihood that the firm can threaten others with reciprocal suit, the firm may be able to avoid rent expropriation from external patent owners or, at least, to minimize its effects.

The paper also represents the first large-scale empirical study of fragmentation in technology markets. Although the "fragmentation index" introduced in this paper is not without flaws, it represents a novel use of patent citations data that highlights the implicit contractual relationship underpinning the citation process. Unlike citations to academic studies, a citation to a previously issued patent does *not* imply a costless right to use the preceding idea, technique, or discovery. Even if negotiations over licenses between the citing and cited entities never occur, characteristics of this pool of potential contracting parties may shape the strategic behavior of firms.

Finally, patents (and patent citations data) have become widely used in management research to trace knowledge flows across organizational boundaries and to test a range of economic, management, and organizational theories about the creation, retention, and transfer of knowledge (Argote et al. 2003, Jaffe and Trajtenberg 2002). If the primary motives for patenting in key industrial sectors are, however, driven by concerns about strategic positioning, it is important to step back and question what is actually being captured in these data. By using backward citations data to reveal some of the uncertainties and transactions costs implicit in the knowledge transfer process, this paper introduces an alternative interpretation of the organizational linkages revealed in these rich databases, inviting further discussion along these lines.

For scholars of innovation and firm strategy, several additional implications arise from this research. First, the ability of firms to identify, absorb, and improve on external technologies and know-how does not necessarily imply that these firms are well positioned to profit from improvements derived from those technologies. As exclusionary rights to new technologies continue to proliferate, it is important to question how these *potential* profits are actually realized by firms. In contexts where firms compete largely on the basis of innovative new products or processes, this suggests that knowledge- and resource-based theories of the firm (Kogut and Zander 1992, Peteraf 1993, Barney 1991) could be informed by more explicit attention to the property rights surrounding intangible assets and the frictions involved in their exchange (Kim and Mahoney 2002). Along these lines, Buchanan and Yoon (2000) conclude that anticommons theory represents "new territory to be explored" for legal scholars and economists. The same may be true for management scholars.

Similarly, a central issue in innovation and technology management is how firms profit from innovation. Since the pioneering work of Teece (1986), the role played by owners of the manufacturing and distribution assets required to bring new inventions to market has received prominent attention in studies of appropriability (e.g., Tripsas 1997, Gans et al. 2002). This study suggests that owners of another important asset—complementary patents—can also affect the profits realized from the commercialization of new technologies. This study also suggests, however, that complementary patent owners pose conceptually distinctive dilemmas for firms, an issue that could be developed more fully in this line of research.

While this paper deepens our understanding of how firms respond to expropriation risks in markets for technology, it is limited in ways that could be addressed in future studies. First, like much of the prior literature, I focus on one mechanism (patenting) in isolation from others. Future research could compare the use and effectiveness of *alternative* mechanisms for safeguarding against patent-related expropriation and explore possible complementarities among them. For example, do firms that invest more heavily in patents also sustain higher levels of R&D spending (therefore buffering against the main prediction of anticommons theory)? Or do increased investments in patenting divert resources and managerial attention away from internal R&D endeavors? These questions are important from both a policy and managerial perspective and warrant additional research.

Another limitation of this study is that it examines the conditions under which firms in one industrial sector, semiconductors, acquire patents to avoid being "fenced in" by outside owners of technology. While this intraindustry approach enables me to disentangle fundamental sources of variation within the industry, it diminishes my ability to generalize these findings to other technological or industrial settings. On one hand, the business risks associated with patent-related hold-up may be elevated for semiconductor firms due to the short product life cycles, the rapid pace of technological change, and the additional complexities and costs associated with commercializing new products within this industry. On the other hand, Cohen et al. (2000) suggest that several of these attributes are shared by other technologically "complex" industries, such as electronics, telecommunications, and computers. Moreover, Cohen et al. (2000) argue that the interdependent nature of technological advances within these industries similarly increases the strategic importance of patents for use in deterring lawsuits, preventing others from blocking access to technologies, and enhancing a firm's bargaining position in licensing negotiations. Future research could sharpen our conceptual understanding of the factors driving common or divergent patterns across sectors, a direction of inquiry that is particularly important in predicting how the allocation of patent rights will affect the development and use of advancements in software, genomics-based research, and Internet-related business methods—areas in which the role of patents remains a topic of considerable controversy and debate.

Exclusionary rights to technological discoveries and ideas shape the overall process of innovation. It is important to understand the broader, strategic value of patents as intangible assets and their intended and unintended effects on the creation and use of new technologies.

An online supplement to this paper is available at mansci.pubs.informs.org/ecompanion.html.

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