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

by

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DON'T FENCE ME IN:

FRAGMENTED MARKETS FOR TECHNOLOGY AND THE PATENT ACQUISITION STRATEGIES OF FIRMS

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ABSTRACT

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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 firms have the legal rights to make, use, or sell technologies they internalize.

Although the challenges firms face in assembling rights to outside technologies have received relatively 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 issuing from the U.S. Patent and Trademark Office (USPTO) in areas from semiconductors and software to human 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 defending against or enforcing 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 this increased acquisition and enforcement of patent rights is creating a problem in technology markets similar to that posed by an "over-fencing" of land (David, 2001): When licenses from too many individual property owners are required, firms may under-invest in the commercialization of downstream technologies (Heller and Eisenberg, 1998). Others raise similar concerns about the emergence of "patent thickets," but predict an emergence of institutional solutions such as patent pools, joint ventures, or acquisitions (Merges, 2001; Shapiro, 2001; Graff et al., 2003).

This paper examines the conditions under which an aggressive patenting strategy is an alternative mechanism 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 transaction 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 upon 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.

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 Section 3), I use linkages revealed in patent citations data to identify some 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

[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

"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 pre-date and follow reforms that strengthened US 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 upon 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. It 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 "pro-patent" shift in US 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 upon 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

(2002) discuss these trends in more detail and review the related literature.

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 the mechanisms firms use to safeguard their investments. In Section 2, I discuss hold-up problems in the markets for patented technologies, draw parallels with the traditional transaction cost literature, and develop three main hypotheses. Section 3 introduces the fragmentation index, while Section 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 problems in markets for patented 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, a hold up occurs when one party is able to expropriate rents from another. A fundamental insight from transaction cost economics is that simple market contracts do not adequately safeguard against expropriation when investments in specific assets are involved, that is, assets cannot be redeployed to the next best use or user without significant loss of value (Klein et al., 1978). Transaction cost theory predicts firms will either (a) internalize transactions involving highly specific assets (i.e., "make" instead of "buy"), or (b) under-invest 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 upon the rights of others. That is, it is an exclusionary, 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 upon 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 "buy" 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. 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. 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."[2]

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., 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 (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).[3] The underlying idea is that granting too

[2] "Experts Claim Merced Infringes S3 Patent", *Global News Wire*, October 17, 1998
[3] Heller (1998, 1999) examines this so-called "tragedy of the anticommons" in the context of real property (e.g., the use of retail stores in post-communist Russia). Heller and Eisenberg (1998) extend the theory in a critique of patents on genetic sequences and receptors used to screen potential drug targets.

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 "anti-commons" (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). 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 patented by 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 illustrate 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 upon 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. Consider the firm's decision to negotiate rights to use these technologies with the respective patent owners prior to building the fab. Under Scenario 1, assume the 1,000 patents are all assigned to one firm. Under Scenario 2, assume those patents are assigned to 1,000 different entities. In a Coasian setting of zero transaction costs, of course, firms could engage in efficiency-enhancing trades, regardless of how the initial entitlements were distributed. Once we assume non-trivial transaction costs, however, differences in the bargaining costs under the two scenarios may influence how firm respond to expropriation risks posed by outside patent owners.

Consider Scenario 1. Given the stakes involved, it is reasonable to expect the manufacturer will 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 patent owner's technology 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 technology from each owner before investing in or building upon 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 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 *ex ante* contracts 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* contracting.

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 transaction 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 under-invest in innovation (a central hypothesis in Heller and Eisenberg's 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 transaction 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 don't 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 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 as 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.

H1: The more fragmented the external technology markets, the more aggressively firms will patent (beyond what is otherwise predicted).

Furthermore, an aggressive patent acquisition strategy should 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. Within the semiconductor industry, the business risks associated with patent-related expropriation are particularly high for firms that own and operate complex manufacturing facilities. As discussed more fully in Hall and Ziedonis (2001), semiconductor manufacturing is notoriously complex; state-of-the-art facilities are expensive to build yet depreciate rapidly, while decisions about the design, layout, and processes used in these facilities are required years prior to product launches during which time many outside patents could issue. 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 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:

> *H2: The effects of fragmented external rights on the patenting behavior of firms will be especially 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. During the 1980s, a "pro-patent" shift took place in the United States that strengthened the legal appropriability regime for patent owners (as mentioned earlier and discussed in Jaffe, 2000 and Gallini, 2002). In particular, the Court of Appeals for the Federal Circuit, a centralized appellate court formed in 1982, increased the evidentiary standards required to invalidate patents, halted allegedly infringing actions earlier in the dispute process through preliminary injunctions, and sustained large damage awards thereby increasing the penalties associated with acts of infringement. The plaintiff success rates in patent infringement suits also increased substantially during the 1980s.

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 appropriability regime:

H3a: The effect of fragmented external rights on incentives to patenting will be stronger following the "pro-patent" shift in the U.S. legal environment (all else equal).

H3b: The interaction effect between fragmented rights and capital intensity will be stronger following the "pro-patent" 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 lacking due to a lack of reliable measures. An ideal measure would characterize the technologies used or built upon by a firm and identify those 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 non-patented discoveries the invention has advanced upon, revealing technological linkages across generations of inventions (Jaffe and Trajtenberg, 2002).

To estimate whether an individual firm draws upon technologies that are widely distributed, I use backward citations to construct a "fragmentation index" as follows:

$$Frag_i = 1 - \sum_{j=1}^{J} \left(\frac{NBCITES_{ij}}{NBCITES_i} \right)^2, \quad i \neq j$$

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, non-patented materials, and expired patents are excluded from the measure as 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 (and therefore few citations listed in those patents). To correct for this statistical bias and assuage concerns that the index is functioning as a lagged indicator of patenting, I normalize the index following Hall (2002):

$$\hat{F}_i = \left(\frac{NBCITES_i}{NBCITES_i - 1} \right) Frag_i$$

where $NBCITES_i$ is the total number of citations listed in patents assigned to each firm's patents (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 (say, 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*

[4]My use and interpretation of the fragmentation index is similar in spirit to an index 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" among legislators delays the speed with which they reach agreement.

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 anti-commons theory). In turn, we predict that 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, 1998). A costless exchange is by no means assured.

Even though this citation-based measure enables me to identify a pool of potential licensors specific 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 patent 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 build upon or 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 would favor particular types of firms (e.g., by degree of capital-intensity) or years within the sample (e.g., during the pro-patent 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 effects 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

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[5] See Jaffe and Trajtenberg (2002) for an extensive discussion of the uses and interpretation of these 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

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 upon 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 "pro-patent" shift in the US legal appropriability regime.

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

licensing efforts and to identify possible licensees." [http://www.mogee.com/services/tl.html; last visited on June 16, 2003]. Other IP consulting firms, such as InteCap and Delphion, market similar services.

[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

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 MicroPatent CDRoms. 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 were 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 during 1975-1996, 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, when assignee and inventor names are unavailable in electronic form. The remaining 82,350 citations (excluding pre-75 cites and self-cites) were manually linked to more than 6,000 unique assignees or inventors and used to calculate an annual fragmentation index for each firm in the sample.[8]

The estimation sample is based on observations during 1980-1994, generating 667 observations on 67 firms.[9] As shown in Table 1, the median firm in the sample has 570 employees, spends $4.83

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nearly 12% of sales. Both figures outweigh corresponding data for leaders in industries such as chemicals, pharmaceuticals, aerospace, and autos (calculated from Compustat data).

[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. I constructed a table of the most frequently cited entities in five-year intervals to verify that my approach generated a reasonable set of semiconductor patent owners. The table, available upon request, 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

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 was 0.52, with a predictable range between 0 and 1. In 44% of the observations, however, a firm did not receive a patent in a given year, and the fragmentation index was reported as missing. As shown in Panel B of Table 1, omitting missing observations of the fragmentation index would generate a sample of larger firms that spend more on R&D and obtain more patents. In order 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 the dummy variable (DFRAG). Estimations based on the restricted sample in Panel B did not substantively alter the econometric results, as shown below.

4.2. Model Specification and Variables

To estimate each firm's propensity to patent, I follow a well-established tradition in the 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}:

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

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 US 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.

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

To estimate how fragmented external rights affect a firm's propensity to acquire patents, it is important to establish a baseline model that controls for well-known predictors of patenting. Two key control variables 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 due to 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 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 millions of $1992). To avoid confounding the R&D and size effects, R&D spending is normalized by the 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.

[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 (available upon request).

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

- **Capital-intensity**, measured as the logarithm of the ratio of the deflated book value of a firm's property, plant, and # 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:

- An 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*Ln Cap Intensity), as defined above.

Finally, to test Hypotheses 3a and 3b, I split the sample into years before and after the strengthened US 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 1985-6 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 1985-86, announcing "A Change in the Legal Climate" (*Forbes*, Oct. 7, 1985, p. 41); "A Weapon at Last [pro-patent decisions]," (*Forbes,* Mar. 10, 1986, p. 46); and "The Surprising New Power of Patents," *(Fortune*, June 23, 1986, p. 57). I therefore divide the sample into periods that pre-date 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 (1980-94) and in Table 3 for the "before" and "after" sub-periods. 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 interaction term. Including the fragmentation index in Column 2 substantially improves the overall fit of the model and significantly 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 under Hypothesis 2. Interestingly, 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, -.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 the sample and is positive only for above-mean values of fragmentation (at values $\geq .75$). 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 provides

[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.
[13] The sign is positive for values of lnCapInt$\geq$1.26, or 99% of the observed distribution.
[14] That is, 22.57 (exp(3.16)-1) is 5.05 times greater than 4.47 (=exp(1.70)-1).

indirect evidence in line with Hypothesis 2: Firms building upon 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 US 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 1980-94: 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.

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

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. If true, we should expect the productivity of these firms' R&D spending to rise with increasing levels of fragmentation. In unreported 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). The results were also robust to the inclusion of 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 a three-year moving average of the fragmentation index.[16]

A third 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. As shown in Columns 7 and 8, however, the main results hold, even allowing for such additional unobservable firm-specific effects. The size of the coefficient on the

[16]The results were robust to using moving averages that ranged from two to four years and that included and omitted one-year lags. Use of a moving average is vulnerable to the criticism that the measure is correlated with unobserved environmental variables, which could exaggerate its estimated effect. The coefficient on Frag*Ln Cap Intensity in Column 6 is indeed slightly larger in magnitude (2.130 v. 1.850) than the otherwise identical model in Column 4. I therefore report the more conservative results using point estimates.

interaction term (FRAG*lnCapIntensity) drops slightly, but is still significant at the 1% level or greater.[17] In unreported regressions, the results also were robust to alternative sources of unobservable permanent fixed-effects (using a "pre-sample" instrumental variable approach) as well as unobserved time-varying effects (using lagged values of the dependent variable).[18] These and all other unreported results discussed above are available upon request.

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 was well-established (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 sub-period. Again, patent propensity estimates are generated using maximum likelihood methods, the negative binomial model, and "robust" standard errors.

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[17] The random effects specification (Column 7) assumes that the unobserved firm-specific effects are uncorrelated with the independent variables. In contrast, the fixed-effects specification (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.)

[18] The "pre-sample" approach, developed by Blundell, Griffith, and Van Reenen (1995), has been used in several recent studies of innovation rates in the strategy literature (e.g., Stuart, 2000 and Ahuja and Katila, 2001). In line with recent studies, I construct the pre-sample 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 (discussed in Ahuja and Katila, 2001) for both the Poisson and Negative Binomial specifications. Including pre-sample patents and lagged measures of the dependent variable (separately or jointly) did not alter key findings presented in Table 2.

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 "pro-patent" regime (supportive of the hypothesis that capital-intensive firms responded strategically to the legal reforms by accumulating 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 utilize myriad, fragmented external technologies. Indeed, when rights to technologies used by a firm are extremely fragmented under the strengthened enforcement regime, capital-intensity is an even stronger, positive predictor of patenting than previously estimated. To see this, compare the .54 coefficient of capital-intensity in Column 2A with the larger total slope coefficient .69 (=2.138-1.444), implied by Column 2B when the fragmentation index is at its maximum value of 1. The size of the coefficient on the interaction term (Frag*LnCapInt) is almost twice as large (2.138 v. 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) are not driven by capital-intensive firms per se, but by the subset of firms that build 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, especially modern invention, is a drama...enacted upon a crowded stage" (Polanyi, 1944). 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 distribution of ownership rights among these actors affects the patenting decisions of firms. I argue that the decision to acquire patents is one important mechanism through which firms respond to the combined contractual hazards posed by "hold up" and fragmentation in external markets for IP. When the costs and potential delays associated with *ex ante* contracting render such an approach infeasible, firms acquire patents as one way of safeguarding their investments *ex post* (e.g., by threatening reciprocal suits or improving their negotiating positions in licensing agreements). The current debate in the theoretical literature has focused on more extreme cases whereby firms either under-invest in technology or resolve such dilemmas through the acquisition of firms or formal institutional solutions (as suggested by Merges, Merges and Nelson, and Shapiro, among others). This paper helps bridge the current divide in this literature by (1) isolating two dimensions of the contracting problem in markets for intellectual property (the bargaining costs and potential delays associated with *ex ante* contracting, as measured by the degree of fragmentation in external markets for technology, and the potential costs associated with being "held up," as measured in this industrial setting by capital-intensity) and (2) showing how these two dimensions *interact* to shape firm behavior.

This paper also introduces a proxy for "fragmented external rights," a construct that has escaped empirical scrutiny despite its prominence in the theoretical literature. Although the specific measure employed for this purpose 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 invention of the original patent owner. Even if negotiations over license agreements between the citing and cited entities never occur, characteristics of this pool of potential contracting parties may shape the strategic behavior of firms.

A limitation of this paper is, like much of the prior literature, its focus on one mechanism (patenting) in lieu of 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 anticipated anti-commons effect)? Or do increased investments in patenting divert resources and managerial attention away from internal R&D initiatives? These questions are both important and remain unanswered. Finally, to what extent are the results of this paper unique to the semiconductor industry (and if so, why)? Similar concerns have been raised in software, genomics-based drugs and agricultural products, and internet-related business methods, yet our understanding of the role and use of patents in these areas remains limited. The exclusionary rights to technological discoveries and ideas play an important role in the overall innovation process. As scholars of innovation and technology management, it is important for us to understand the broader, strategic value of these intangible assets.

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Table 1: Sample Statistics

A: Sample Used in Estimation 667 Observations (67 Firms) 1980-1994					
Variable Name	**Mean**	**S.D.**	**Median**	**Min**	**Max**
Patent Applications	17.56	58.88	1.00	0.00	565.00
R&D Spending ($M 1992)	39.00	112.28	4.83	0.00	1061.40
R&D Intensity* ($M 1992 R&D/1000 employ)	6.68	1.38	7.10	0.00	134.74
Employment (1000s)*	0.64	1.76	0.57	0.02	89.88
Capital intensity* ($M 1992 bk value PPE/ 1000 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					
Variable Name	**Mean**	**S.D.**	**Median**	**Min**	**Max**
Patent Applications	31.45	76.06	6	0	565.00
R&D Spending ($M 1992)	69.35	143.35	14.68	0	1061.40
R&D Intensity* ($M 1992 R&D/1000 employ)	10.18	1.13	11.47	0	134.74
Employment (1000s)*	1.44	1.71	1.25	0	89.90
Capital intensity* ($M 1992 bk value PPE/ 1000 employ)	37.89	0.68	37.38	3.12	165.60
Fragmentation Index	0.89	0.11	0.92	0	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.

Table 2: Negative Binomial (NB) Estimates of Determinants of Patenting, 1980-94 (67 US Semiconductor Firms)

	Base Model & Main Results			Robustness Checks				
							Unobserved Heterogeneity	
Variable Name	Base (Pooled NB) **(1)**	Add Frag (Pooled NB) **(2)**	Full (Pooled NB) **(3)**	Addl Control Tech Oppty (Pooled NB) **(4)**	Restricted Sample (Pooled NB) **(5)**	Replace Frag Indx with 3 yr ma. (Pooled NB) **(6)**	Random Effects (Panel NB) **(7)**	Cndl Fixed Effects (Panel NB) **(8)**
Intercept	Year Dummies	Year Dummies	Year Dummies	Year Dummies	Year Dummies	Year Dummies	Year Dummies	Year Dummies
Frag * Ln Cap Intensity			1.848*** (.464)	1.850*** (.463)	5.025*** (1.642)	2.130*** (.526)	1.135*** (.360)	1.001** (.403)
Fragmentation Index		1.465** (.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** (.912)	-3.381*** (.900)	-3.381*** (.901)	--	-3.703*** (1.026)	-3.453*** (.646)	-2.926*** (.683)
Tech Opportunity (Ln # impt. patents)	--	--	--	.678** (.245)	2.073** (.733)	.591*** (.183)	.533** (.179)	.572** (.211)
Ln Capital Intensity ($M 1992 PPE/empl)	.505*** (.153)	.316*** (.153)	-1.379*** (.411)	-1.380*** (.410)	-4.403** (1.662)	-1.563*** (.428)	-.968** (.334)	-.937** (.378)
Dummy, Texas Instr.	.827*** (.239)	1.023*** (.216)	1.074*** (.237)	1.073*** (.237)	1.096*** (.252)	.982*** (.237)	3.333*** (.634)	--
Dummy, missing R&D	-.836 (1.025)	.815 (.669)	.878 (.644)	.872 (.643)	1.618* (.624)	.869 (.612)	.245 (.762)	-.206 (1.923)
Ln R&D intensity ($M 1992 R&D/empl)	.493*** (.106)	.273*** (.097)	.286*** (.087)	.286*** (.089)	.297*** (.086)	.368*** (.092)	.245*** (.067)	.171 (.099)
Ln firm size (1000s employees)	.905*** (.060)	.711*** (.053)	.705*** (.052)	.705*** (.057)	.698*** (.062)	.776*** (.059)	.412*** (.054)	.348*** (.063)
δ (Variance Parameter)	.662 (.111)	.418 (.065)	.401 (.059)	.400 (.058)	.381 (.148)	.514 (.079)	--	--
Log-Likelihood	-1438.8	-1253.9	-1242.6	-1241.5	-1193.1	-1333.81	-1219.4	-979.6
N	667	667	667	667	372	667	667	667
Chi-squared (p-value)		136.34 (.000)	15.84 (.000)	7.67 (.005)	8.43 (.001)	42.67 (.000)	93.14 (.000)	79.51 (.000)

* $p < .05$; ** $p < .01$; ***$p<.001$

Notes:

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 vs. the previous nested model in Columns 2-4 and vs. 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 did not receive patents during sample period.

Table 3: Fragmented Rights and Incentives to Patent, "Before" and "After" Strengthened Enforcement Regime (36 Incumbent Firms, 1980-85 v. 1986-94)

	Period 1: "Before" 1980-85				**Period 2: "After" 1986-94**			
Variable Name	Base (1A)		Full (1B)		Base (2A)		Full (2B)	
Intercept	Year Dummies		Year Dummies		Year Dummies		Year Dummies	
Frag * Ln Cap Intensity			1.143*	(.572)			2.138***	(.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 ($M 1992 PPE/empl)	.116	(.273)	-1.313**	(.516)	.540***	(.193)	-1.444**	(.547)
Dummy, Texas Instr.	1.036*	(.342)	1.325***	(.258)	0.739**	(.282)	.850**	(.248)
Dummy, missing R&D	.835	(.936)	2.187***	(.559)	-26.262***	(.676)	-20.842***	(.755)
Ln R&D intensity ($M 1992 R&D/empl)	.554*	(.237)	0.605***	(.148)	.377**	(.124)	0.168	(.109)
Ln firm size (1000s employees)	0.867***	(.089)	0.614***	(.081)	0.919***	(.077)	0.763***	(.064)
δ (Variance Parameter)	.632 (.278)		.241 (.087)		.531 (.099)		.343 (.064)	
Log-Likelihood	-327		-253.8		-843.9		-749.1	
N	185		185		362		362	
Chi-squared (p-value)			28.4 (.000)				48.92 (.000)	

* $p < .05$; ** $p < .01$; ***$p<.001$

Notes:

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.