Combining Patent Law Expertise with R&D for Patenting Performance

Deepak Somaya†, Ian O. Williamson‡ and Xiaomeng Zhang*
† College of Business, University of Illinois at Urbana-Champaign
‡Melbourne Business School and the Intellectual Property Research Institute of Australia, The University of Melbourne
***American University**

Intellectual Property Research Institute of Australia
Working Paper No. 06/08
ISSN 1447-2317

November 2008

We would like to thank seminar participants at the Academy of Management and the Maryland-Georgetown summer series for helpful comments on earlier drafts. Wilbur Chung, Gary Dishnitsky, Brent Goldfarb, Curt Grimm and Violina Rindova provided valuable comments. We are especially grateful to Jim Hirabayashi, Jim Miller, Robert Martindale, Ogden (Slim) Webster and Cecil Quillen for help and suggestions with the research. Bilen Aynu, Kevin Bravo-Ferrer, Jiun-Jie Chou, Francisco Estrada, Drina Harrison, Nisha Mehta, and Anuj Trivedi provided able research assistance. We gratefully acknowledge research seed funding from the R. H. Smith School of Business and support from the Intellectual Property Research Institute of Australia (IPRIA). The first two authors contributed equally to this project.

Intellectual Property Research Institute of Australia
Alan Gilbert Building, The University of Melbourne
Parkville Victoria 3010
Australia
Tel: +61 3 8344 2100
Fax: +61 3 8344 2111
Email: info@ipria.org
Web: www.ipria.net

Abstract

Drawing on the resource-based view that firm performance is often the outcome of resource bundling, in this paper we examine how the combination of firm resources influences firm innovation performance. We hypothesize that firm innovation, specifically patenting output, depends not only on R&D, but also on complementary patent law expertise required to identify and develop inventions, and convert them into patents. Furthermore, we predict that this effect is moderated by top management team (TMT) functional background and industry conditions, which influence the ability of firms to perceive and act on resource combination opportunities. We empirically model the patenting performance of a sample of Fortune 500 firms from 1990 to 2000 using count panel data techniques, and find robust support for our hypotheses. Our findings shed light on how non-R&D resources affect firm innovation performance, and advance the integration of the resource-based view with complementary organizational perspectives.

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INTRODUCTION

A central and enduring question in the study of organizations is: why do firms differ in terms of performance? According to the resource-based view (RBV), performance differences can be attributed to the unequal distribution of resources across firms (Barney, 1991). Resources, in this sense, refer to all existing firm assets, both tangible and intangible, whose services can be used to achieve organizational goals (Penrose, 1959; Wernerfelt, 1984). Firms that possess resources that are valuable, unique, immobile, and difficult to imitate are theorized to derive competitive advantages that can produce higher levels of performance (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993).

One approach a firm can use to generate competitive advantage from its resources is to combine them in different ways to create new products and services that provide economic rents (Penrose, 1959). As Penrose notes, "Exactly the same resources when used for different purposes or in different ways and in combination with different types or amounts of other resources provides a different service or set of services" (1959: 25). The creation of such new products and services is in essence "innovation". Innovation has been defined as a process that encompasses both the creation of new ideas and the harnessing of this new knowledge to create formal capabilities (Nonaka & Takeuchi, 1995). Research on firm innovation performance, specifically patenting performance, has largely focused on the role of one resource, firm research and development (R&D), which has been shown to have a significant positive relationship with innovation (Griliches, 1990; Hall & Ziedonis, 2001; Nicholls-Nixon & Woo, 2003). However, while R&D is an important resource for creating technological *inventions*, other complementary resources may be essential for harnessing these inventions to increase firm innovation output. Yet, to date, questions remain about which related resources should be combined with R&D to enhance innovation output, or what types of contextual factors allow such resource combinations to maximize innovation. These are important limitations in the literature because a greater understanding of the resource combination process can provide deeper theoretical insights into how resources generate value for organizations (Moran & Ghoshal, 1999). In addition, examining these issues may hold practical implications for organizational leaders attempting to formulate strategies for enhancing firm innovation.

In this paper we attempt to address this gap in the literature by studying how R&D resources needed for the generation of new technical inventions are combined with firm patent law expertise, which we theorize is essential for converting these novel ideas into tangible innovation outputs, specifically patents. We argue that these legal resources are necessary to elicit, collate, and evaluate patentable inventions, and to navigate the legal intricacies of the patent process. While prior work has shown that firms can increase innovation output by using new R&D to build upon existing stocks of R&D (Penner-Hahn & Shaver, 2005), there is an absence of research examining how different types of resources may be combined to gain competitive advantage.

There is also a lack of research examining what role, if any, contextual factors might play in shaping the innovation outcomes associated with resource combinations. We hypothesize that even when firms possess high levels of patent law expertise, patent output is contingent upon whether intra-organizational and external environmental conditions facilitate the combination of these resources with R&D. Drawing on upper echelon theory, we predict that if organizational leaders have a patent law background, this will increase the effectiveness with which firms combine this resource to produce patents. We also hypothesize that differences between industries in the strategic value placed on building large patent portfolios will influence the likelihood that firms successfully combine legal and R&D resources to increase innovation output.

Our study makes two important contributions. First, we extend the innovation literature by examining how firms' strategic choices to deploy and combine different types of resources are an important predictor of firm innovation performance. To our knowledge, this represents the first study of the impact that legal resources, in combination with R&D, have on firm patenting. Second, our paper extends RBV theory by examining how contextual factors at both the organizational- and industry-levels of analysis can influence the effectiveness of resource combination for innovation. Thus, our study responds to the call of Moran and Ghoshal (1999) for an exploration of the "structures and processes" necessary for resource combinations to create value (p. 409). More broadly, this paper addresses the pressing need for integrating the resource-based view with complementary organizational perspectives (Barney and Zajac, 1994; Barney, 1997).

We examine these issues by longitudinally studying the patenting performance of 101 U.S. Fortune 500 firms from 1990 to 2000. We focus on patent output because patents are tangible manifestations of firms' ideas, techniques, and products (DeCarolis & Deeds, 1999), and represent an important milestone in the innovation process within firms. Furthermore, patenting performance has frequently been used to measure firm innovation in past research (Ahuja & Katila, 2001; Hall and Ziedonis, 2001; Griliches, 1990). There is also substantial evidence for a robust positive link between patent output and various measures of the overall performance of firms; for example, firm market valuation (Pakes 1985; Griliches, Pakes & Hall, 1987; Griliches, Hall & Pakes, 1991; Hall, Jaffe and Trajtenberg, 2005), firm sales (Bloom & Van Reenen, 2002), and firm profitability (Markman, Espina, & Phan, 2004). The 1990-2000 time frame is well suited to studying predictors of firm patenting performance because it followed a significant pro-patent shift in the legal environment, which led to sharp increases in U.S. patenting (Kortum and Lerner, 1999; Rivette and Kline, 2000).

THEORY AND HYPOTHESES

R&D and Firm Innovation

The resource-based view (RBV) suggests that a key determinant of a firm's performance is whether or not the firm has accumulated the appropriate types of resources (Penrose, 1959; Wernerfelt, 1984; Barney, 1991). In examining which resources enhance innovation performance, extant research in management and economics has primarily focused on firms' stocks of knowledge accumulated through R&D. R&D is seen as an input into the production of a firm-specific knowledge resource, which in turn facilitates the identification, assimilation and exploitation of information generated both within and outside the firm (Cohen & Mowery, 1984; Cohen & Levinthal, 1990). For example, Nicholls-Nixon and Woo (2004) report a significant positive relationship between R&D expenditures and patent output in pharmaceutical companies. The authors conclude that R&D activities help firms develop knowledge capabilities, which in turn lead to patents. A well-established tradition in the economics of innovation has also adopted a similar view of the relationship between R&D and patenting (Pakes and Griliches, 1980; Hausman, Hall and Griliches, 1984; Hall, Griliches and Hausman, 1986; for a review, see Griliches, 1990). In this literature, R&D expenditures "are considered to be investments which add to the firm's stock of knowledge," (Hall, Griliches, and Hausman, 1986: 265) which leads to firm innovation in the form of patents.

Therefore, while the creation of new ideas may be serendipitous, firms that invest in their knowledge resource stock through R&D increase their odds of making innovations because they develop a more fertile setting for finding novel solutions to challenging problems. Thus, greater commitment to R&D should result in greater flows of innovation from the organization. Since the role of knowledge resources in innovation is well-established, we focus our hypotheses on the role of related resources that must be combined with R&D, and contextual factors that may influence this resource combination process.

Combination of Legal Resources with R&D

An important assumption underlying past research examining the relationship between firm R&D and innovation is that novel ideas generated by R&D will automatically be converted into tangible innovation outputs. While R&D may lead to the *invention* of new technologies, there may be barriers to the *harnessing* of these new ideas for the creation of firm competitive advantage, both of which are important for innovation (Nonaka & Takeuchi, 1995). Despite inventing new technologies, a firm may not derive significant competitive advantages unless it is also able to patent these technologies. Technical inventions may not get translated into patents because the true commercial value of novel ideas and practices is often difficult to ascertain (Moran & Ghoshal, 1999), and firms may lack the expertise to balance these uncertainties against the costs of patenting.[1] Firms also need the capability to assess which patents will be most useful as isolating mechanisms (Rumelt, 1984; Somaya, 2003). Finally, firms need

[1] Current estimates for worldwide patent coverage, including maintenance costs, are in the range of $100,000 per patent.

specialized resources to conduct prior art searches and to draft effective patent applications. Thus, firm R&D may best be thought of as increasing the patenting *potential* of a firm, while other resources may be important for translating this potential into patent output.

One such resource that may be particularly effective for increasing firm patenting, when combined with R&D, is patent law expertise. In research-driven firms, very large numbers of potentially patentable inventions are generated, and it isn't always evident how many, or which, of these inventions should be patented. In part, this is fostered by the esoteric and complicated nature of patent law. A firm's patent law expertise can provide strategic input into which technologies firms should and should not attempt to patent, and at what stage of a technology's development patents should be filed. Furthermore, the success of patent applications is not guaranteed; only about two-thirds of patent applications filed are granted in the U.S. Patent law expertise enables firms to generate better patent applications and to file and revise them quicker, thus increasing the odds that they will ultimately be successful. Within firms, patent law expertise resides essentially in the knowledge and capabilities of in-house patent attorneys.[2] Patent attorneys are required to have a bachelor's degree in a technical field and pass the patent bar exam, which sets them apart from other lawyers. Due to these requirements, there are only a limited number of qualified patent attorneys in the U.S., and only these individuals can practice before the U.S. Patent Office. Thus, patent law expertise is both a unique and rare organizational resource, and provides value by enabling firms to convert a greater number of inventions into patents.

Encapsulating the ideas presented so far, we theorize that firms can enhance patenting output by harnessing complementarities between two types of resources (Teece, 1986; Conner, 1991; Lippman and Rumelt, 2003), in-house patent law expertise and R&D. There may be significant advantages to combining firm R&D with internal, as opposed to external, patent law expertise. Internal patent attorneys are likely to be more specialized in the firm's technological areas versus external attorneys, and have a better understanding of the firm's unique patenting strategy. In-house patent attorneys are also likely to

[2] When we use the term "patent attorneys", we include both patent attorneys and patent agents. Patent agents do not have a law degree, but are otherwise similarly qualified as patent attorneys.

have better relationships with inventors, engineers, and other key players within the firm. By virtue of these relationships, internal patent attorneys may have access to privileged information critical for identifying patentable inventions and translating them into patents. Even in those cases where patenting work is outsourced, in-house patent law expertise may play an important role in managing the outsourcing relationship.

The idea that resources are deployed in bundles or combinations has been a consistent theme in the resource-based literature, beginning with Penrose (1959:25). In prior work on innovation, researchers have studied complementarities between different types of R&D (Penner-Hahn and Shaver, 2005), and the influence of complementary assets on the technological focus of firm R&D (Helfat, 1997). However, we are unaware of any research that has examined how the combination of different types of resources, in particular the combination of legal resources with R&D, influences firm innovation output. Building on the logic presented above we predict:

Hypothesis 1: The higher the level of patent law expertise that is combined with firm R&D, the greater will be the firm's innovation output.

Contextual Factors

So far, we have examined how the combination of patent law expertise with R&D is likely to enhance firm innovation output. However, despite its theorized potential to enhance firm innovation, the mere possession of these legal resources by a firm may not be sufficient to generate more innovation. In order for resources to generate value they must typically be deployed in some purposeful manner (Moran & Ghoshal, 1999). Absent such deployment, a gap may exist between the productive potential of a firm and its realized performance. Penrose argues that firms only bridge this gap when they perceive available productive opportunities and are willing and able to act on them (1959: 32). Thus, it may not be the level of R&D and patent law expertise per se, but whether firms recognize the value of increasing patenting and their ability to effectively coordinate these resources that is a determinant of firm innovation output. Building on this logic, two factors which may make the combination of R&D and patent law expertise more effective at generating patents are: 1) top management team (TMT) patent-law background and 2) patenting pressures in a firm's industry.

TMT Patent-law background

The TMT of a firm is the group of decision makers primarily responsible for making key decisions about the allocations of firm resources and for coordinating the deployment of these resources (Hambrick & Mason, 1984). Therefore, the background and expertise of managers in the TMT is likely to have an impact on the effectiveness of resource combinations. According to upper echelon theory "organizational outcome(s)—both strategies and effectiveness—are viewed as reflections of the values and cognitive bases of powerful actors in the organization" (Hambrick & Mason, 1984: 193). This perspective is based on the idea that when organizational leaders, such as TMT members, make complex strategic decisions they are likely to be influenced by their prior experiences and behaviors (March & Simon, 1958). These prior experiences both inform executives about what alternative strategies are available to firms, and shape their beliefs about the likely consequences associated with each alternative (Hambrick & Mason, 1984).

In particular, one type of experience that is theorized to play an important role in shaping executives' strategic choices is their functional background (Hambrick & Mason, 1984). Each member of the TMT brings to his or her job an orientation that is significantly influenced by the activities and goals of their prior functional domains. Thus, executives' functional expertise is likely to influence how they frame a strategic problem and how it is to be solved. The functional expertise of TMT members can play an important role in determining whether or not they perceive a benefit in increasing specific innovation outputs, and whether or not they understand the need for combining certain resources to achieve those outputs.

Members of the TMT are in a position to draw managerial attention to goals that they believe are important and influence strategies for achieving those goals. Therefore, TMT members' prior experiences influence key decisions about the focal goals and strategies adopted by the firm. If TMT members have a patent law background, the firm may be more likely to focus on patents as a source of competitive advantage. Moreover, TMT patent experience may be invaluable in improving the effectiveness with which legal resources are combined with R&D to generate patents. TMT members with a patent-law background can play a critical role in supporting the organizational coordination of R&D and patent law expertise. By virtue of their position within the company, these executives are uniquely positioned to break down barriers between R&D units and in-house patent attorneys, and develop channels for engineers and patent lawyers to communicate with each other.

We are unaware of any research that has examined how TMT characteristics influence the performance of specific resource combinations within firms. However, several studies have found an association between TMT characteristics and the overall strategic direction of firms (e.g., Thomas, Litschert, & Ramaswamy, 1991; Wiersema & Bantel, 1992; Barker & Mueller, 2002), thus, supporting the idea that the cognitive makeup of TMT members influences the deployment of firm resources. Based on the rationale presented above we predict:

Hypothesis 2: The combinative impact of patent law expertise on firm innovation output will be stronger when firms have TMT members with a patent law background.

Industry Patenting Pressures

While the background of TMT members may be an important internal influence on the effectiveness of resource combination, this can also be affected by external environmental pressures on the firm. Industry conditions can make certain organizational outcomes such as increasing patent output more or less valuable to firms, and in turn influence the amount of attention firms give to achieving these outcomes versus other competing goals (Moran & Ghoshal, 1999). In such industry settings, firms are also likely to face pressures from key external providers of resources to pursue these value-adding objectives (Pfeffer and Salancik, 1978). These factors can motivate firms to overcome internal organizational barriers and more effectively coordinate the combination of its resources. In the context of patenting, we would expect firms in industries with high patenting pressures to be more successful in translating patent law expertise, along with R&D, into patent output.

In systems-based industries like electronics, computers, semiconductors, and machinery, products tend to consist of a very large number of inventions that come from many disparate sources (Cohen, Nelson, & Walsh, 2000). Conversely, products in materials-based industries (e.g., pharmaceutical and chemical) tend to consist of discrete atomistic inventions, or a small set of closely related inventions (Cohen et al., 2000). As a result, products in systems-based (compared to materials-based) industries are much more likely to infringe on patented technologies previously or even simultaneously being developed by other companies (Grindley & Teece, 1997). With the significant strengthening of patent rights in the 1980s,[3] unwitting patent infringement became a major concern for firms operating in systems-based industries due to the associated risks of very large damage awards or even the shutting down of an entire business (Hall and Ziedonis, 2001).

In this type of patent environment, significantly increasing firm patenting provides several advantages that are unique to systems-based industries (Hall & Ziedonis, 2001). Large patent portfolios are invaluable tools for firms to defend themselves against patent enforcement by making counter-threats to sue back their patent-wielding rivals (Somaya, 2003). In addition, the patents can be used as trading chips in ex-ante cross-licensing deals, where two companies exchange reciprocal licenses to each other's patent portfolios (Grindley & Teece, 1997). Thus, the building of patent portfolios in systems-based industries helps firms maintain the "design freedom" to use external patented technologies when developing their own products. Because products in systems-based industries use such large numbers of inventions, patents also provide systems-based firms with significantly more opportunities to earn royalties for use of their technologies than materials-based firms.

These economic factors are likely to place greater pressures on firms in systems-based industries, as opposed to materials-based industries, to aggressively pursue patenting. Therefore, systems-based firms are likely to emphasize increasing their patent output, and be more effective in overcoming organizational barriers to achieving this goal. For these reasons, the odds of firms realizing the patent

[3] This shift has been well documented in prior work (Kortum and Lerner, 1998; Hall and Ziedonis, 2001), and was primarily due to the creation of a new pro-patent Appeals Court (the Federal Circuit).

production potential associated with combining R&D and legal resources may be greater in systems-based, compared to materials-based, industries.

Hypothesis 3: The combinative impact of legal resources on firm innovation will be stronger for firms in industries that experience higher pressures for innovation performance.

Data and Methods

Sample

We tested our hypotheses on a panel data set of public U.S.-owned firms that were in the *Fortune* 500 list in 1990. Our theory is primarily relevant to firms that are likely to engage in technological innovation, and to patent their inventions. Therefore, we only included firms from industries that fit this profile, and excluded services and mature industries from our sample. The sampling frame consisted of all 1990 *Fortune* 500 industrials classified by *Fortune* as being in the following five broad industry groupings: chemicals (49 firms), computer manufacturing (22 firms), electronics (44 firms), pharmaceuticals (12 firms) and scientific and photographic equipment (17 firms), for a total of 144 firms. Of these 144 firms, 15 were excluded from the sample because they were subsidiaries of foreign firms or were not publicly traded. In addition, a total of 28 firms were dropped from the analysis due to missing data. Thus, hypotheses tests were conducted using an unbalanced panel (due to acquisitions, mergers, dissolution, or being taken private) of 101 firms tracked over the period 1990-2000. To clarify, the unit of observation in our analyses was firm-year, and all variables were measured for each firm in each year.

Dependent Variable

Firm Innovation Performance. The measured firm innovation performance as the count of all granted U.S. patents filed by the firm in a given year. Our use of patent counts to measure innovation performance is consistent with several previous studies of firm innovation (e.g., Griliches, 1990; Ahuja & Katila, 2001; Hall and Ziedonis, 2001; Penner-Hahn & Shaver, 2005). For each firm, we compiled the entire corporate family (including subsidiaries, divisions, and affiliates) using the Directory of Corporate Affiliates for each year. We used the PATSIC Database of the U. S. Patent and Trademark Office (USPTO) to match patents to each firm for each year by employing the codes assigned by the USPTO to patenting entities within a firm's corporate family. Thus, our methodology is similar to the much larger NBER patent database (Hall, Jaffe, and Trajtenberg, 2001), with the difference that the NBER database relies on corporate families aggregated in a single year (1989), while we track changes (which are quite common) over time.

Independent Variables

R&D. R&D was measured using the total R&D financial expenditures reported for each firm in a given year. Our use of this measure is motivated by the finding that when firm effects are included, the impact of lagged R&D values on patenting is rendered insignificant (Hall, Griliches & Hausman, 1986). Thus, same-year R&D expenditures contain almost all the information about knowledge inputs into patenting, and it is not possible to use lagged R&D to separately measure the stock of accumulated knowledge resources (Hall, Griliches & Hausman, 1986). To ensure that our R&D variable doesn't simply proxy firm size, we divided R&D expenditures by the number of firm employees. Firm R&D expenditures data were gathered using the Research Insight database, which was also the source for firm size (employees). The GDP deflator was used to convert R&D expenditures (and other dollar-denominated financial data) into 2000 dollars.

Patent Law Expertise. The firm's patent law expertise was measured as the total number of U.S. patent attorneys and agents that were employed within a firm's corporate family in a given year. Patent attorneys must maintain their registration (and current address) with the Office of Enrollment and Discipline (OED) of the USPTO in order to practice before the office. Because the OED aggressively enforces the requirement that attorneys maintain their current address,[4] we used the official addresses in the USPTO patent attorney database to determine the number of attorneys employed by each firm in our sample in a given year. We validated our approach by examining a sample of 100 patent attorneys listed on patents from our dataset, and found that our technique correctly coded the attorney's employer in all

[4] The office goes so far as to frequently audit a random selection of attorneys, and revoke the registration to practice of those that do not have a current address on file.

98 cases for which we were able to independently identify the employer. Again, to account for correlation with firm-size, we divided this variable by the number of firm employees.

TMT Patent Background. We measured the patent background of a firm's TMT by coding whether or not at least one member of a firm's TMT was a patent attorney (coded 1 if yes, 0 if no). Consistent with previous research, we compiled a list of firm TMT members using the *Dun & Bradstreet's Reference Book of Corporate Management*, which also contains the professional biographies of the listed TMT members (Carpenter, 2002; Williamson & Cable, 2003; Jensen & Zajac, 2004). We used both these biographies and the USPTO patent attorney database to determine if a firm's TMT contained a patent attorney in a given year. We also ran the analysis using the total number of patent attorneys in a firm's TMT, which made no significant difference to our results. Since our hypothesis argues that TMT patent background would *enhance* the combinative effect of legal resources on innovation, we interact this variable with patent law expertise to test hypothesis 2, and incorporate the raw variable in the analyses as a control.

Firm Industry. As discussed earlier, we expect that the pressures to increase patenting output strengthened significantly in systems-based industries following the patent reforms of the 1980s. We follow prior research in classifying firms into systems-based and materials-based industries using their primary 4-digit SIC code (Kusunoki, Ikujiro, & Nagata, 1998; Cohen, Nelson & Walsh, 2000; Hall, 2004). We also felt it important to distinguish between high-tech systems industries, where the patent infringement problem may be more acute because innovation and patenting are progressing at a much faster pace, and mature systems industries (Kusunoki, Ikujiro, & Nagata, 1998). Accordingly, we coded two industry dummy variables, which we label *systems-hi-tech* (computers, electronics, medical devices/equipment, analytical and photographic equipment), and *systems-mature* (electrical and mechanical machinery, office equipment), respectively. The base category consists of materials-based industries (chemicals, pharmaceuticals), where innovation is generally atomistic. Since we employ fixed-effects panel data techniques, we do not use raw industry dummy variables to avoid misidentification, and only use the interaction of these variables with legal resources (which is consistent with our hypothesis).

Control Variables

To provide better estimates of the hypothesized variables described above, we included several control variables in the analyses. First, to account for the possibility that large firms may generate greater numbers of patents because they have more resources, we used two measures of firm size; *number of employees* and *sales* (deflated by the GDP deflator into 2000 dollars, and normalized per 1000 employees). Because of skewness in the number of employees, and the exponential functional form of our empirical model, we used the log value of the variable. Data on firm sales and number of employees was gathered using the Research Insight database. Next, to account for the possibility that firm-years with no patent attorneys may be qualitatively different from other firm-years (i.e. left censoring of the Patent Law Expertise variable) we included a dummy variable labeled *zero attorney dummy* in our analysis, which was coded "1" for observations with no patent attorneys and "0" otherwise. Finally, because we measured patenting performance through the identity of the patent's assignee when it was granted, there is a concern that we may not accurately capture the patenting of firms that are subsequently merged into or acquired by another firm. The patents applied for by these firms may issue in the name of their acquirer or the merged entity. To account for this possibility we include two dummy variables labeled *M&A Dummies (prior year and two years)*, which identifies whether a firm in our sample merged or was acquired in the next year or in two years, respectively. Data on firm mergers and acquisitions was gathered using *Hoovers On-Line*.

Empirical Model

Our empirical approach follows a long tradition of studying patenting in economics beginning with Scherer (1965), and subsequently developed by Zvi Griliches and his co-authors. Recent work in this stream has appropriately pursued the use of count data models for estimating patent output (Hausman, Hall & Griliches, 1984; Hall and Ziedonis, 2001; Ahuja and Kattila, 2001), which has the following basic specification for the mean:

$$E(Patents) = \exp(X\beta) \qquad \ldots \qquad \text{(i)}$$

This mean-specification is typically transformed for count data by employing the Poisson model. The Poisson distribution assumes that the mean and variance of the errors are equal, which can lead to biased estimates in some contexts, especially with cross-sectional data. One frequently employed remedy to address this issue is the negative binomial distribution, which allows means and variances to be different and thus accommodates over-dispersion in the data. However, it has been shown that the Poisson estimator is consistent for panel-data models even if the underlying distribution in the data is not truly Poisson so long as the mean specification is accurate (Gourieroux, Monfort and Trognon, 1984). Other estimators like the negative binomial are inconsistent if the true distribution of the errors is not as hypothesized (Gourieroux, et al., 1984). Therefore, consistent with other studies that have examined patent output using panel data techniques (Hall and Ziedonis, 2001; Ahuja and Katila, 2001), we employ the Poisson estimator in our empirical analyses.

In addition to the fact that the Poisson model yields consistent estimates with panel data techniques, potential concerns about over-dispersion are alleviated for two reasons. First, in count panel-data models, prior research has demonstrated that a very significant portion of the over-dispersion is accounted for when unit specific (random or fixed) disturbances are allowed (Hausman, Hall & Griliches, 1984). Because we employ a fixed-effects Poisson model, the fixed effects would substantially account for potential over-dispersion in the data. Second, we shield against any residual over-dispersion by estimating "semi-robust" standard errors, which are consistent even if the variance is incorrectly specified so long as the model specifies the mean correctly.

To test our hypotheses we used a fixed-effects (as opposed to random-effects) model. Our decision to use a fixed effects model is based on the fact that we have a non-random sample of *Fortune* 500 firms. Moreover, there is potential for unobserved heterogeneity in our data, which may cause a random effects model to be mis-specified because the unit (firm) level disturbances are correlated with the regressors (Greene, 2000). Count-data fixed effects models can be estimated by conditioning out the fixed effects using the sum of within-unit counts (Hausman, Hall & Griliches, 1984). But, a limitation of the conditional fixed-effects model is that it cannot accommodate alternate correlation structures, and in particular, is unable to account for potential autocorrelation in the data.

With patent data, it has been demonstrated that one way to account for fixed inter-firm differences is to use the "pre-history" (i.e. before the panel begins) of the dependent variable. This approach is both effective as a fixed-effects technique and enables the use of more flexible correlation structures (Blundell, Griffith & Van Reenen, 1995). We employ this pre-history fixed effects Poisson model, and adopt an AR(1) correlation structure to allow for serial correlation in firm patenting. We accounted for firm patent pre-history by using the total number of patents (transformed by logs) granted to the firm in the five years before the start of our panel (1985-1989). We also used year dummies to account for systematic year-specific patenting changes. The model is estimated by the Generalized Estimating Equations (GEE) technique pioneered by Liang and Zeger (1986). In prior management research, Ahuja and Katila (2001) have adopted a very similar approach to our own for modeling patent output.

Results

Hypotheses Tests

The summary statistics for the variables used in our analyses are contained in Table 1. There is substantial "within" variation in our key independent variables indicating significant changes in firm resources and context conditions over time, which we hypothesize are systematically correlated with firm patenting performance. Table 2 contains the correlations between the variables. We see expected high levels of correlation between the TMT Background Dummy variable and the TMT Patent Background X Patent Law Expertise variable. Apart from this, there is also strong correlation between R&D Resources and Sales (0.52), between patenting pre-history and the zero attorneys dummy (0.53), and between patenting pre-history and size (0.72). Since none of these are a primary independent variable, this is not a major concern for the analysis.

[Table 1 and Table 2 about here]

Since our empirical model is in exponential form, our key variables enter in a multiplicative fashion. To illustrate, we can expand our basic model (i) in the following manner:

$$E(Patents) = [\exp(\beta_1 \times R\&D)] \times [\exp(\beta_2 \times PatentLawExpertise)] \times [...] \times [...] \times$$

Therefore, our model directly incorporates the combinative effect between R&D and Patent Law Expertise. For example, a significant coefficient on Patent Law Expertise would indicate that this variable amplifies the effect of R&D (and other variables in the empirical model) on patenting by a certain ratio. We employ interaction terms to model our contextual factors, which would amplify the combinative impact of Patent Law Expertise on patenting in specific contexts. Thus, to examine the impact of TMT patent background and industry on resource combination effectiveness, we interact these variables, respectively, with Patent Law Expertise.

Our main results are reported in Table 3. The variable coefficients are shown in exponentiated form, which can be interpreted as relative risk ratios (akin to odds ratios).[5] Thus, coefficients that are greater than "one" indicate a positive effect, whereas coefficients less than "one" indicate a negative effect. Column (1) contains estimates from the base model with the R&D variable and most control variables. We estimate the two control variables associated with specific main effects (Zero Attorneys Dummy and TMT Background Dummy) only when the corresponding main variables are also included. The base model (1) conforms to expectations. Patenting performance depends on size (measured both by employees and sales), but also on the level of firm R&D. Further, firm fixed-effects as measured by patenting pre-history and the M&A dummies are significant.

[Table 3 about here]

Hypothesis 1 predicts that the combination of patent law expertise with R&D would lead to a significant increase in innovation performance, as measured by patent output. However, as illustrated in column (2) of Table 3, the coefficient of the Patent Law Expertise variable, while greater than "1", was not significant at conventional levels. Thus, Hypothesis 1 was not supported.

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[5] However the significance tests are conducted on the raw coefficients because their distribution, unlike the distribution of exponentiated coefficients, is symmetric and well characterized.

In Hypothesis 2, we postulated that TMT expertise would increase the combinative impact of patent law expertise on patent output. In column (3), as well as in the full model in column (5), we find strong evidence to support this hypothesis. Firms with TMT members having a patent-law background were significantly more likely (at the 0.05 level) to successfully combine their legal resources with R&D to generate patents. When firms have a TMT member with a patent-law background, an increase in legal resources from zero to one (attorneys per 1000 employees) increased patent output by 39.1% in model (3) and 37.0% in model (5). Interestingly, the mere presence of TMT members with a patent-law background is not a significant predictor of patenting performance; reinforcing the idea that TMT background helps translate potential resource combination opportunities into innovation instead of influencing innovation directly.

Columns (4) and (5) provide strong evidence that firms in systems-based industries were significantly (at the 0.01 level) more likely than firms in materials-based industries to generate patents through the application of complementary legal resources. Not only does this result provide support for Hypothesis 3, but it also clarifies that this effect is specific to high-technology systems-based industries rather than mature systems-based industries. In high-technology systems-based firms, an increase in legal resources from zero to one (attorneys per 1000 employees) increased patent output by 74.8% in model (4) and 68.4% in model (5). Overall, while patent law expertise does not significantly enhance firm patenting in all situations, it can have a substantial impact on patenting output when certain internal organizational or external industry attributes are present.

Robustness Checks

In Table 4, we report the estimated coefficients from four additional econometric models to evaluate the robustness of our empirical results. In column (1) of Table 4 we reproduce the full model from Table 3 for comparison. Columns (2) and (3) contain estimates of a conditional fixed effects Poisson model and a random effects Poisson model, respectively. In column (4), we report estimates from a model identical to column (1), but with a trimmed sample that excluded the top and bottom 5% of firms based on their patenting performance. We include this model to ensure that our results are not being driven by outlier observations. Across all three of these models, we found the same pattern of results as our main results in column (1), with the exception that in the conditional fixed effects and random effects models the coefficient for the mature systems-based industry is also significant. However, we would advocate caution in interpreting these coefficients because, as discussed above, our main model provides a more conservative statistical test.

[Table 4 about here]

One potential concern about our results is that our specific categorization of firms into systems- and materials-based industries may have biased our results. In column (5), we address this concern by employing an alternate industry variable based on technology groupings of patents, which has been widely used in patent research (e.g. Jaffe, Fogarty, and Banks, 1998). Using U.S. patent classes, we measured the fraction of the firm's patents from the prior three years in two key systems-based technology groups – "medical devices", and "electronics, computers/ communication, optical and nuclear" (ECON) – and used them in lieu of our industry dummy variables. We found very similar effects with these alternate industry variables, and no significant effects (not reported) for other technology groups ("drugs", "chemicals", "mechanical", "other"). Overall, our robustness checks provide us with greater confidence in our hypotheses tests.

Discussion and Conclusion

Innovation is critical for firms to develop sustainable competitive advantages. To date, an extensive body of research has examined how the use of one type of firm resource, R&D, influences firm innovation output (e.g., Hall, Griliches & Hausman, 1986; Hall & Ziedonis, 2001; Nicholls-Nixon & Woo, 2003). However, while some research has examined the combination of different types of R&D, no research has examined how *other* complementary resources, such as legal resources, may be combined with R&D to generate innovation. Extant research has also not examined how contextual factors might influence the relationship between firm resource combinations and innovation output. Our results provide evidence that TMT background and industry pressures influence the ability of firms to leverage patent-law expertise for increasing patent output from their R&D. These findings provide insight into the importance of legal resources, in addition to R&D, for firm innovation. Furthermore, we extend RBV research by demonstrating how intra-organizational and external environmental factors affect the effectiveness with which firms can combine resources.

Legal Resources in Innovation

A key finding of our paper is that the combining of R&D resources with patent law expertise enhances the patent output of firms; albeit only in specific firm and industry contexts. While prior work has suggested the potential importance of internal legal resources in increasing patenting (Hall and Ziedonis, 2001), to our knowledge this is the first study to empirically examine the effect of legal resources on firm patenting performance. Our finding is consistent with RBV predictions that the combination of complementary resources contributes significantly to firm competitive advantage over and beyond the contribution of any one resource (Lippman & Rumelt, 2003; Moran & Ghoshal, 1999). The results also support our conceptualization of patenting as an innovation process that contains two necessary components, the creation of novel ideas with the potential to generate new capabilities, and the transformation of these ideas into tangible outputs with economic value. Thus, while R&D is needed to generate new technologies, the hiring of patent attorneys may provide firms with the unique legal expertise that enables them to identify more patentable technologies and navigate the patent process more effectively, resulting in greater patent output. While our specific focus in this paper was on patent law expertise, our findings suggest the potential for other complementary resources to enhance the innovation performance of firm R&D.

Multi-Level Contextual Factors

A second important contribution of this study is the finding that firm-level and environmental-level factors influence innovation by increasing the effectiveness with which firms capitalize on resource combination opportunities. Prior research on innovation has tended to focus on the level of resources accumulated within firms and not on the context in which they are deployed. Our strong results regarding the role of firm and environmental factors challenge this focus, and emphasize the importance of examining contextual conditions to gain a richer understanding of the determinants of firm innovation performance. More broadly, the findings of this study support prior theorizing that contextual factors play an important role in determining the extent to which resource combinations create value for firms (Barney 1997; Moran & Ghosal, 1999).

At the firm-level, we found that when a firm's TMT contained at least one member with prior experience in patent law, this increased the number of patents generated from R&D through the use of legal resources. This finding is consistent with the upper echelon perspective that TMT members, based on their prior experiences, shape and direct how firm resources are utilized (Hambrick & Mason, 1984). TMT members with patent law background may be more likely to view patenting as an important organization goal, and be able to bring greater organizational focus to this goal. These TMT members may also be able to create structures within the firm that facilitate the coordination between R&D and patent attorneys.

Thus, our findings illustrate how the human capital of key decision makers can provide firms with sustained competitive advantages in the area of innovation. While possessing complementary resources may improve firms' innovation output, in order to realize the innovation potential of these combinations firms must have decision makers who are knowledgeable about how these resources can and should be combined. Our findings build upon an emerging stream of research applying the upper echelon perspective to the study of innovation. While prior work has shown that TMT attributes influence the research orientation of firms (Barker & Mueller, 2002), our findings demonstrate that TMT members also play a significant role in influencing the effectiveness with which resources are used to generate innovation. Future research may benefit from further investigation of the relationship between TMT characteristics and firm innovation.

Industry-level pressures also influenced the effectiveness with which legal resources were employed to generate patents from firm R&D. Compared to firms in materials-based industries, firms in high-tech systems-based industries generated significantly more patents by leveraging their patent law expertise. This finding extends innovation research by demonstrating that the effectiveness with which resources produce innovations may vary across competitive environments. Industry pressures may induce firms to focus on specific innovation goals, which in turn can create an impetus for organizational mechanisms that facilitate the conversion of inventions into innovation output.

The experience of Hewlett-Packard (HP), one of the firms in our sample, provides an illustration of how firms in systems-based industries may leverage legal resources to respond to industry pressures. As an electronics company, HP competes in an industry where products typically contain numerous inventions that are patented by many different companies. Consequently, an important strategic consideration for HP since the 1980s has been maintaining design freedom and avoiding accidental infringement (Grindley & Teece, 1997). To manage this situation, the company developed a formal intellectual property decision process for determining how to handle the patenting of all R&D developments. As part of this process all R&D output are examined by an internal committee with input from engineers and internal legal experts. Mechanisms such as these allowed the company to identify technological areas to stress for patent protection and to make decisions about the best method of protecting each invention (Grindley & Teece, 1997). Thus, in response to industry pressures, HP sought ways to combine its patent law expertise more effectively with R&D to increase patenting. This qualitative example, along with our empirical findings, demonstrates that increasing innovation output is not simply a function of resource accumulation, but is contingent upon the macro-institutional context within which these resources will be utilized (Oliver 1997).

Limitations and Future Research

While our findings hold important implications for our understanding of innovation, this study is not without limitations, which may provide excellent opportunities for future research. First, while we provide initial evidence that the build-up of legal resources in particular contexts is important for firm innovation, understanding when and how firms decide to acquire this resource is beyond the scope of this paper. While this does not invalidate our main findings, future work could examine the factors that lead to the development of patent-law expertise within firms. This is a particularly interesting question because our results suggest that acquiring additional patent attorneys may not enhance patenting in all contexts.

We theorize that to be effective the requisite patent-law expertise should be situated within the firm. This approach is based on the idea that firms benefit from in-house patent attorneys who are specialized to the firm's area of technological focus and have privileged access to information and personnel within the firm. However, firms can also retain the services of law firms in order to gain access to external patent-law expertise. Future research could build upon the findings of our study by explicitly examining the factors that influence firm choice between internal and external legal resources. Furthermore, research can also examine whether the use of internal versus external patent law expertise has a differential impact on firm innovation output.

Finally, our study focuses on large *Fortune* 500 firms. However, in many industries, small and mid-sized firms are often important producers of innovation (Kortum & Lerner, 1999; Grindley & Teece, 1997). Yet, small and large organizations represent different organizational forms, which may face different resource constraints. For example, due lower levels of resources, it may be difficult for small technology firms to maintain a large number of patent attorneys on staff. As such, small firms may rely to a greater extent on external legal resources. Furthermore, compared to large firms, small firms may be more heavily pressured by institutional norms due to a need to garner resources from external constituents (e.g., investors, customers) (Aldrich & Auster, 1986; Hall, 2004). Thus, future research can extend this study by examining the extent to which our model applies to small- and mid-size firms and how such firms can actually enhance their innovation output.

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Table 1: Variable Descriptive Statistics

Variable	Obs	Mean	Standard Deviation			Min	Max
			Overall	Between	Within		
Patenting Performance (count)	1077	158.6	336.1	295.9	137.2	0.0	3864.0
R&D ($ Mn per 1000 employees)	998	13.88	12.83	11.59	5.80	0.09	96.05
Patent Law Expertise (Attorneys per 1000 employees)	1058	0.44	0.43	0.39	0.16	0.00	2.39
Patent Law Expertise Interacted with:							
TMT Patent Background	1058	0.07	0.23	0.18	0.14	0.00	1.95
Systems (Hi-Tech) Industry	1058	0.17	0.28	0.26	0.09	0.00	1.64
Systems (Mature) Industry	1058	0.03	0.12	0.11	0.05	0.00	1.35
Zero Attorneys Dummy	1141	0.18	0.38	0.36	0.16	0.00	1.00
TMT Background Dummy	1141	0.10	0.30	0.24	0.18	0.00	1.00
Log Patent Pre-history	1129	4.93	1.68	1.70	0.00	0.69	8.21
Sales ($ Mn per 1000 employees)	1058	223.7	117.3	104.2	49.1	56.6	1021.8
Log Firm Size (in 1000 employees)	1058	2.94	1.05	1.01	0.27	0.11	5.92
M&A Dummy (prior year)	1141	0.02	0.15	0.07	0.15	0.00	1.00
M&A Dummy (two years)	1141	0.02	0.15	0.06	0.14	0.00	1.00

Table 2: Correlation Table

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	Patenting Performance	1.00												
(2)	R&D	0.20	1.00											
(3)	Patent Law Expertise	0.15	0.35	1.00										
	Pat. Law Exp. Interacted with:													
(4)	TMT Patent Background	(0.03)	0.01	0.27	1.00									
(5)	Systems (Hi-Tech) Industry	0.32	0.29	0.28	0.19	1.00								
(6)	Systems (Mature) Industry	(0.09)	-0.20	0.02	-0.07	-0.16	1.00							
(7)	Zero Attorneys Dummy	(0.19)	-0.22	-0.44	-0.13	-0.26	-0.11	1.00						
(8)	TMT Background Dummy	(0.04)	-0.02	0.17	0.88	0.18	-0.07	-0.14	1.00					
(9)	Log Patent Pre-history	0.52	0.17	0.46	0.05	0.24	0.04	-0.53	0.05	1.00				
(10)	Sales	0.16	0.52	0.40	0.02	0.07	-0.15	-0.17	-0.04	0.11	1.00			
(11)	Log Firm Size	0.58	0.07	0.07	-0.06	0.05	0.01	-0.39	-0.01	0.72	-0.01	1.00		
(12)	M&A Dummy (prior year)	(0.05)	0.04	-0.06	-0.03	-0.05	0.00	0.02	-0.04	-0.04	0.04	-0.01	1.00	
(13)	M&A Dummy (two years)	(0.05)	0.07	-0.03	-0.02	-0.04	0.01	0.02	-0.03	-0.03	0.03	-0.03	-0.02	1.00

Table 3: Pre-History Fixed Effects AR(1) Poisson Models of Patenting Performance

	Dependent variable = Number of Successful Patents Filed				
	(1)	(2)	(3)	(4)	(5)
R&D	1.010**	1.009**	1.009**	1.010**	1.010**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Patent Law Expertise		1.245	1.212	1.038	1.020
		(0.189)	(0.183)	(0.180)	(0.179)
Patent Law Expertise Interacted with:					
TMT Patent Background			1.391*		1.370*
			(0.201)		(0.188)
Systems (Hi-Tech) Industry				1.748**	1.684**
				(0.256)	(0.245)
Systems (Mature) Industry				0.977	0.988
				(0.266)	(0.272)
Zero Attorneys Dummy		0.822*	0.816*	0.837*	0.832*
		(0.071)	(0.071)	(0.072)	(0.071)
TMT Background Dummy			0.891		0.885
			(0.101)		(0.093)
Log Patent Pre-History	1.400**	1.315*	1.314*	1.293*	1.297*
	(0.130)	(0.141)	(0.142)	(0.129)	(0.131)
Sales (per 1000 Employees)	1.001**	1.001**	1.001**	1.001**	1.001**
	0.000	0.000	0.000	0.000	0.000
Log Firm Size (1000 employees)	2.045**	2.203**	2.197**	2.202**	2.199**
	(0.224)	(0.289)	(0.288)	(0.276)	(0.278)
M&A Dummy (two years)	0.841*	0.848*	0.847*	0.834*	0.834*
	(0.064)	(0.064)	(0.064)	(0.067)	(0.067)
M&A Dummy (prior year)	0.704**	0.711**	0.711**	0.692**	0.692**
	(0.080)	(0.082)	(0.081)	(0.086)	(0.085)
Year Dummies	Yes	Yes	Yes	Yes	Yes
Rho (autocorr.)	0.93	0.93	0.93	0.90	0.90
Observations	980	980	980	980	980
Number of Firms	101	101	101	101	101
Wald Chi-squared	363.1**	425.6**	439.2**	758.4**	754.5**

Standard errors in parentheses are “robust”
Significance: * = 5%; ** = 1%

Table 4: Robustness Checks on Panel Data Poisson Models of Patenting Performance

	Dependent variable = Number of Successful Patents Filed				
	Full Model from Table 3 (1)	Fixed Effects Poisson (2)	Random Eff. Poisson (3)	Trimmed 5% Sample (4)	Industry Tech. Grps. (5)
R&D	1.010**	1.004**	1.004**	1.012**	1.010**
	(0.003)	0.000	0.000	(0.003)	(0.003)
Patent Law Expertise	1.020	0.995	1.004	1.111	0.899
	(0.179)	(0.029)	(0.029)	(0.202)	(0.173)
Patent Law Expertise Interacted with:					
TMT Patent Background	1.370*	1.373**	1.380**	1.483**	1.330+
	(0.188)	(0.062)	(0.062)	(0.186)	(0.210)
Systems (Hi-Tech) Industry	1.684**	1.783**	1.780**	1.541*	
	(0.245)	(0.069)	(0.068)	(0.275)	
Systems (Mature) Industry	0.988	4.514**	4.278**	0.858	
	(0.272)	(0.592)	(0.557)	(0.254)	
E.C.O.N. Tech. Share					2.256**
					(0.375)
Medical Devices Tech. Share					2.639**
					(0.769)
Log Patent Pre-History	1.297*			1.261*	1.326**
	(0.131)			(0.138)	(0.133)
Sales (per 1000 Employees)	1.001**	1.001**	1.001**	1.001+	1.001**
	0.000	0.000	0.000	0.000	0.000
Log Firm Size (1000 employees)	2.199**	2.445**	2.453**	2.135**	2.162**
	(0.278)	(0.033)	(0.033)	(0.346)	(0.268)
Zero Atty. Dummy	Yes	Yes	Yes	Yes	Yes
TMT Bckgd. Dummy	Yes	Yes	Yes	Yes	Yes
M&A Dummies	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes
AR(1) Auto-correl.	Yes	No	No	Yes	Yes
Robust Std. Err.	Yes	No	No	Yes	Yes
Observations	980	998	998	899	980
Number of Firms	101	103	103	92	101
Wald Chi-squared	754.5**	13031.9**	13211.9**	659.8**	898.9**

Significance: + = 10%; * = 5%; ** = 1%