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Human Capital, Social Collaboration, and Patent Renewal Within U.S. Pharmaceutical Firms

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Human capital has received much attention as the microfoundation for a firm to achieve competitive advantage. For knowledge-intensive firms, inventors' human capital plays an important role in developing intellectual assets such as patents. Little research, however, has explored how inventors' human capital influences the firm's decisions of which patent to maintain or to abandon. This study investigates the effects of inventors' human capital and collaboration characteristics on patent renewal decisions in the context of U.S. pharmaceutical firms. The results show that having star inventors on the inventor team, having more coinventors, and having inventors from multiple locations significantly increase chances of patent renewal. In addition, having more coinventors positively moderates the effects of star inventors on patent renewal. Implications for research are discussed.

Keywords: *strategic human capital; patents and R&D strategy; knowledge management*

Human capital has received much attention because human capital lays the microfoundation for a firm to achieve competitive advantage (Barney & Wright, 1998; Coff & Kryscynski, 2011; Nahapiet & Ghoshal, 1998; Ployhart & Moliterno, 2011). Prior research has shown that human capital is critical to firm performance, such as financial performance (Hitt, Bierman, Shimizu, & Kochhar, 2001; Reed, Lubatkin, & Srinivasan, 2006), product and service innovations (Subramaniam & Youndt, 2005), and patent output (Rothaermel & Hess,

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2007). In the context of innovation, inventors' human capital plays an important, constructive role in developing a firm's intellectual assets such as patents because inventors contribute important knowledge to the firm (Grant, 1996; Rothaermel & Hess, 2007; Subramaniam & Youndt, 2005).

While prior research has established the link between inventors' human capital and inventions, the effects of inventors' human capital on how to manage a portfolio of patents are less explored. Helfat and Peteraf (2003) suggest that a firm has an ongoing task of growing, maintaining, and sometimes streamlining its portfolio of resources and capabilities. In the context of patent portfolio, the firm has a task of adding new patents and sometimes abandoning existing patents. The firm needs to determine whether some patents are valuable enough to be worthy of further maintenance and development while others are no longer valuable and have to be abandoned, a decision known as patent renewal (Harhoff, Narin, Scherer, & Vopel, 1999; Liu, Arthurs, Cullen, & Alexander, 2008). Prior research on patent renewal explored how technological indicators of patent value influence the strategic decision of patent renewal (Harhoff et al., 1999; Liu et al., 2008; Moore, 2005). Little research, however, has investigated how inventors' human capital influences a firm's strategic choices on patent renewal, an intrafirm decision beyond the sole influence of technological determinants. Since inventors are the key contributors of knowledge underlying patents, their human capital characteristics should provide important inputs to firms' decision making on patent renewal.

This study seeks to fill this gap by investigating effects of inventors' human capital and their collaboration characteristics on the firm's patent renewal decisions. This study focuses on the impact of high-performing individuals such as star inventors (Campbell, Ganco, Franco, & Agarwal, 2012; Hess & Rothaermel, 2011; Oettl, 2012; Zucker, Darby, & Brewer, 1998). Like prior research on star inventors (Hess & Rothaermel, 2011), we identify the presence of star inventors on the inventor team. For social collaboration among inventors, we examine characteristics such as the inventor team's size and geographical dispersion. We suggest those organizational characteristics of the inventor team indicate the extent to which inventors pool complementary knowledge in creating patents. In addition, we argue that more coinventors who collaborate with star inventors would be able to leverage star inventors' human capital within the firm. We suggest these human capital characteristics of inventors would influence the firm's strategic decisions of patent renewal. We tested our hypotheses with a sample of 284 U.S. public pharmaceutical firms.

Theory and Hypotheses

Human capital has recently attracted growing attention from both strategy and human resources scholars. The human capital of employees has been considered as a pivotal contributor to a firm's competitive advantage (Barney & Wright, 1998) because human capital is often intangible, firm specific, and socially complex (Hatch & Dyer, 2004). As employees often collaborate with one another, recent research often characterizes human capital as a collective or "unit-level" resource (Ployhart & Moliterno, 2011). As human capital of individual employees often works in conjunction with other employees' human capital, the coupling of human capital, that is, whether there is complementarity (Ethiraj & Garg, 2012; Somaya, Williamson, & Zhang, 2007) or synergy (Sundaramurthy, Pukthuanthong, & Kor, 2013), is critical to the best utilization of human capital. In other words, a firm needs to understand not only the individual differences among human capital of different employees, but also how best to provide the appropriate intrafirm context under which human capital can best function. In the context of technological inventions, we need to explore not only individual-based human capital of inventors, but also how inventors can best complement each other and recombine their knowledge effectively.

While inventors provide valuable human capital to the firm, their human capital is semi-permanently attached to the firm because inventors may leave the firm and take their human capital away (Campbell, Coff, & Kryscynski, 2012; Coff, 1999). The value inventors create for the firm, therefore, is best solidified in the intellectual assets they have created for the firm, including patents, publications, and products. The value of patents has dual components—the public value and the private value. Once patents have been created, according to patent laws in the United States and other major industrial countries, inventors need to publicize the contents of patents and specify how they have made progress on prior inventions and knowledge. This part of the value goes to the public domain and benefits all participants in the community, often referred to as knowledge externality or knowledge spillover (Jaffe, 1986; Jaffe, Trajtenberg, & Henderson, 1992). We refer to this part of value as the public value of patents.

In the meantime, the private component of patent value mostly benefits the owner of patents only, not the general public. Once granted, patents represent the owner's legal right to exclude others from using that innovation (Lanjouw & Schankerman, 2004). Such exclusive ownership is conferred to the owner as a reward for her or his prior investment on R&D. The private value allows the owner to capture economic value, exclude competitors from appropriation, and seek returns to her or his earlier investments (Moore, 2005; Pakes, 1986; Reitzig, 2004).

A patent's public value is related to but different from its private value. Whereas the public value of patents may benefit all participants in the technological community, the private value of patents has a sole beneficiary—the owner only. While the public value of patents represents how the public views the technological importance of patents, the private value is more related to economic returns of the firm. Temporally, the public value of a patent is created as soon as the patenting system has granted the patent. By contrast, granting is only the beginning of the management of a patent's private value, which is a continuous process in which the firm's managers and legal attorneys play an important role (Moore, 2005).

Prior research has established that patents vary greatly in the private value. Because patents are seldom marketable and value determination is illusive, research has relied on indirect indicators of patent value, one of which is patent renewal (Harhoff, Scherer, & Vopel, 2003; Liu et al., 2008; Moore, 2005; Pakes, 1986; Reitzig, 2004). In the U.S. patent system, after issuance of the patent, the owner (a large entity such as a publicly held firm) is expected to pay $900 at the fourth year, $2,300 at the eighth year, and $3,800 at the twelfth year. Failure to make these payments results in expiration of patents. The small amount of money needed for patent renewal pales in comparison to financial resources available at established firms, financial resources required in the patenting process, or the expenses and potential rewards from a patent lawsuit. When selected patents are not renewed, the owner firm gives up legal ownership and the private value of those patents dissipates because the firm cannot seek private interests or economic returns from those expired patents. The expiration of such patents represents strategic decisions of the firm's managers or legal attorneys (Moore, 2005).

The firm's evaluation of the private value of the patented invention drives the renewal decision—a patent is either renewed when the firm expects to be able to capture value from the patent or abandoned when the value of holding the patent is lower than the costs of maintaining the patent (Harhoff et al., 1999; Liu et al., 2008; Moore, 2005; Pakes, 1986). Patent renewal is a deliberate strategic choice so that the firm could preserve the value of renewed patents. The strategic nature of patent renewal therefore provides us an opportunity to observe how a firm differentiates patents of sufficient private value from other patents of lesser value. Prior studies on patent renewal have identified a variety of determinants that influence patent renewal decisions, such as forward citations, backward citations, claims (Harhoff et al., 1999; Harhoff et al., 2003; Moore, 2005), and some path-dependent factors (Liu et al., 2008).

While prior research has focused mostly on technological determinants of the private value of patents, this study focuses on inventors' human capital as an important driver of the private value, for several reasons. As creators of patents, patent inventors provide important information about patent value. First, knowledge resides within the minds of inventors (Felin & Hesterly, 2007), and the level of inventors' human capital provides a valid indicator of value. Inventors' human capital or their individual knowledge, skills, and capabilities determine whether the patents they have created hold sufficient value for the firm to develop and maintain. Inventors' quality provides informational signals to the firm about the value of patents. In other words, different levels of inventors' human capital differentiate valuable patents from patents of lesser value.

Second, and more important from the perspective of preserving and protecting value by the firm, inventors' contributions go beyond their individual human capital because inventors often collaborate with other inventor colleagues. Such social collaboration positions the firm advantageously for protecting the private value of patents. Social collaboration within the firm's social community of inventors involves complementary knowledge to be shared and utilized in the creation of new knowledge. Complementary knowledge, like other complementary assets, strengthens the firm's position of value protection (Teece, 1986). Although individual inventors are liable to move and take the knowledge with them to their next employer (Campbell, Coff, et al., 2012; Coff, 1999), the chance of such mobility and its deleterious impact on the firm would be much smaller if the firm can keep much of the complementary knowledge within the firm. Using the parlance of exchange value versus use value (Campbell, Coff, et al., 2012), stronger complementary knowledge in creating those patents would increase the use value of inventors' human capital to the focal firm and lower the exchange value of their human capital to other competitors. In other words, the social collaboration among inventors would help to safeguard the private value of patents.

Human Capital of the Invention Team: Having Star Inventors

Individual inventors differ in terms of their education, learning capabilities, knowledge, and expertise. This individual based difference lies at the core of human capital (Becker, 1964; Coff & Kryscynski, 2011; Ployhart & Moliterno, 2011). While inventors may contribute different types of human capital, current research mostly focuses on the group of high performing individuals, often known as star inventors, who sometimes can make disproportionately huge contributions to the development and advancement of science and technology (Hess & Rothaermel, 2011; Zucker, Darby, & Armstrong, 2002). For example, biotechnology stars are those top 0.75% contributors who account for almost 17% contributions to the genetic sequence database GenBank (Zucker et al., 1998). Following prior research, we also focus on the quality differentiation of inventors and discuss the effects of star inventors on patent renewal.

Human capital of star inventors contributes to patent value in at least three ways. First, star inventors can contribute their scientific knowledge and firsthand lab experiences. Research shows that star scientists possess tacit knowledge that is otherwise difficult to access or transfer (Murray, 2004; Zucker et al., 1998). Second, in an indirect way, star inventors help to improve the knowledge of their nonstar collaborators by exposing those nonstars to their tacit knowledge. Nonstar collaborators learn from star inventors by absorbing tacit knowledge and know-how (Azoulay, Zivin, & Wang, 2010; Oettl, 2012). Those collaboration experiences allow nonstars to improve their knowledge and the collective improvement of the inventor team engenders more novel recombination of knowledge.

Third, having star inventors also entails signaling effects. Star inventors enhance the legitimacy of the inventor team as well as the legitimacy of patents the team has created (Luo, Koput, & Powell, 2009). Since the patent renewal decisions cannot wait until full information is available and the firm has to evaluate the private value of the patent with incomplete information available (Moore, 2005; Pakes, 1986), a situation that involves much uncertainty, the legitimacy provided by star inventors gives positive "signals" and would favor the patents created by their teams. Among a portfolio of patents to be considered for renewal, the firm would favor those patents that are created by high-quality human capital and hold higher promises for the firm to create and capture economic value. Therefore, we expect that having star inventors on the inventor team will improve the chances that their patents are considered as having sufficient private value.

Hypothesis 1: Having star inventors on the inventor team increases the chances that their patent will be considered as having sufficient private value to the firm.

Social Collaboration Within the Firm: Complementary Coinventors

Inventors oftentimes work with a number of colleagues in generating knowledge. Such social collaboration provides an important mechanism for screening out inferior ideas early and pooling complementary knowledge. For example, Singh and Fleming (2010) suggest that sole inventors are less likely to generate breakthrough inventions than those inventors working in teams, possibly because sole inventors lack the social process of eliminating bad ideas from the inception of projects. Social collaboration allows inventors to combine their knowledge with complementary knowledge of coinventors. Complementary pieces of knowledge can be pooled together from inventors with different knowledge backgrounds (Palomeras & Melero, 2010).

Complementarity among inventors contributes not only to effective value creation, but also to value protection by the firm. The process of pooling complementary knowledge embeds the knowledge within a complex web of social relationship (Hoetker & Agarwal, 2007; Van de Ven, 1986). In a complementary knowledge creation process, human capital of individual inventors can be cospecialized with the human capital of fellow inventors and the firm's contextual idiosyncrasies (Campbell, Coff, et al., 2012). One individual inventor may not hold all pieces of knowledge that are critical to the knowledge creation because complementary pieces of knowledge reside with coinventors. As the individual inventor may move to competitors, it would be more difficult for competitors to exploit the individual's human capital because other complementary knowledge may remain in the web of social relationships at the focal firm. Complementarity, therefore, would position the firm in a stronger position to protect value (Teece, 1986). For example, Palomeras and Melero (2010) find that an individual inventor is less likely to move to competitors when the degree of complementarity is higher. The degree of complementarity in knowledge creation can be captured in two related but distinct dimensions—the size of inventor team and geographical dispersion. The following subsections explore these two dimensions in detail.

The size of inventor teams. A larger inventor team allows inventors to pool and recombine knowledge from a wider scope of knowledge. As inventors contribute different specialized knowledge to the invention process, the complementary pieces of knowledge can be better recombined together (Palomeras & Melero, 2010). The wider pool of knowledge also allows the inventor team to recombine knowledge in more complex ways (Hoetker & Agarwal, 2007). As the size of the inventor team increases, the loss of one individual inventor may not affect the other complementary components, which from the firm's perspective would enhance the preservation and protection of the private value.

Within the broader firm context, a larger team size represents a stronger social connection with the firm community and a stronger presence of firm-specific knowledge. A larger team increases the chances of social interactions of inventors within the larger social community of the firm and better absorbs firm-specific knowledge into the knowledge creation process. For example, Hoetker and Agarwal (2007) show that because a larger team would create knowledge that is more socially embedded within the firm, a larger team would decrease the patent citations further when the firm exits. Compared with those knowledge assets created by fewer inventors or even a sole inventor at the extreme, the knowledge created by a larger team is more likely to have been shared with and diffused into the wider firm-specific knowledge base (Singh & Fleming, 2010). The stronger connection with the firm community embeds the human capital of the inventor team within a larger social community. For patents created by a larger inventor team, inventors' wider social webs of connections within the firm would allow the firm to have informational advantage in understanding and appreciating the private value of patents because many other inventors outside the team may have gained some understanding via social contacts and informal connections. Therefore, we expect,

> *Hypothesis 2*: The larger size of the inventor team increases the chances that their patent will be considered as having sufficient private value to the firm.

Geographical dispersion of inventors. Complementary knowledge sharing may go beyond one specific location as inventors on the team sometimes are not colocated. In terms of value creation, the inventor team may enhance invention outcomes by utilizing intraorganizational linkages that connect inventors dispersed at different subsidiaries (Lahiri, 2010). First, using intraorganizational linkages puts the inventor team at an advantage to identify and assimilate useful knowledge within the firm network. As inventors share knowledge from different locations of the same firm, inventors share the same organizational milieu and language within the same context of the firm. Such shared knowledge and purpose would ease the difficulties of explaining knowledge, particularly those tacit components of knowledge, and overcome informational inefficiencies of identifying and evaluating knowledge (Lahiri, 2010).

Second, knowledge from different locations often contains novel elements to be recombined into knowledge creation (Almeida & Phene, 2004; Phene, Madhok, & Liu, 2005). Whereas inventors at the same locations often interact frequently and they tend to exhaust possible "local" recombination of knowledge, inventors at different locations may not interact on a daily basis and may have something new to offer to each other. As inventors from different locations collaborate in the team, they are able to share and transfer knowledge in ways colocated inventors may not.

From the perspective of value protection, the geographical dispersion of inventors increases the extent of firm specificity of knowledge that underlies patents. Knowledge can be tacit, "sticky," and location specific (Bell & Zaheer, 2007; Rugman & Verbeke, 2001). As inventors are dispersed in the firm's network of subsidiaries at multiple locations, it enhances the protection over the patented knowledge because location-specific components of knowledge are difficult for competitors to imitate. While competitors may seek to hire away a few key inventors, a geographically dispersed team of inventors is more difficult to steal in whole since dispersed inventors are more likely to be embedded within those specific locations due to noneconomic reasons (Campbell, Coff, et al., 2012). The firm also can enhance its value protection due to its capabilities of organizing and coordinating inventors at multiple locations to collaborate on research projects, which constitute some firm-specific organizing capabilities (Campbell, Coff, et al., 2012). Therefore, when inventors collaborate from multiple locations, the firm can expect a higher private value out of patents from the perspectives of both value creation and value protection.

Hypothesis 3: The cross-location collaboration of the invention team increases the chances that their patent will be considered as having sufficient private value to the firm.

Leveraging star inventors' human capital in a larger team. While human capital of star inventors can be an important determinant of the value of knowledge assets, the effects of star inventors' human capital may not exist in isolation from social contexts. Even stars cannot win battles on their own and need the proper social context. For example, Groysberg, Nanda, and Nohria (2004) show that the performance of star analysts decreased precipitously when they moved from one employer to another, presumably due to the loss of social interactions with previous colleagues. Similarly, Singh and Fleming (2010) suggest that lone inventors, that is, those sole creators of inventions who have no collaborators, are less likely to create breakthrough inventions because lone inventors lack social interactions with peers, a key process in which inventors can eliminate bad ideas and enrich the development of good ones. Coinventors, by contrast, can help star inventors screen out bad ideas early and pool complementary knowledge. More coinventors indicate that human capital of star inventors can be better embedded in the social context of the firm (Hoetker & Agarwal, 2007). The higher degree of social interactions of the invention team would allow star inventors to interact with other inventors both within the team and beyond in exchanging ideas and enriching knowledge.

In addition, when there are more coinventors on the inventor team, the superior human capital of star inventors can better benefit the invention outcome. As discussed before, the importance of a star inventor lies in her or his unique and superior knowledge, particularly tacit knowledge. The learning and transfer of tacit knowledge is often difficult and time-consuming (Zucker et al., 1998). Collaborators of the star inventor are at a fortunate position to access such tacit knowledge via their on-the-job interactions (Azoulay et al., 2010; Murray, 2004; Oettl, 2012). More collaborators on the inventor team would provide a wider and more accessible conduit through which the tacit knowledge of the star inventor diffuses into the firm's social community and knowledge base. In other words, more coinventors would allow the human capital of star inventors to be better leveraged and utilized within the firm (Hitt et al., 2001; Sirmon, Hitt, & Ireland, 2007). Therefore, we expect that positive effects of the human capital of star inventors to be stronger when they work with a larger team.

Hypothesis 4: The larger the team of inventors of the patent, the more positively the presence of star inventors increases the chances that their patent will be considered as having sufficient private value to the firm.

Method

Sample

To test these hypotheses, we collected data from the U.S. pharmaceutical industry between 1990 and 2004. We chose this industry because patents have been considered important intellectual assets of pharmaceutical firms that rely on patent portfolios to gain competitive advantage (Levin, Klevorick, Nelson, & Winter, 1987). The success of pharmaceutical firms depends on the successful maintenance of patents to establish and continue their monopoly of key knowledge. The pharmaceutical industry provides an interesting context to explore our research question where pharmaceutical firms make strategic choices about what specific patents to renew when the private value of those patents seems to be critical to their success. The sample included 284 pharmaceutical firms, and we collected their financial data from Compustat.

We constructed a patent data set based on all successful patent applications by these firms granted between 1990 and 2004, drawing upon the database created at the Kauffman Foundation known as COMETS (Connecting Outcome Measures in Entrepreneurship Technology and Science); the Kauffman Foundation extracted their raw data from the U.S. Patent and Trademark Office (USPTO) but offered a fully computerized database (Zucker, Darby, & Fong, 2011). The COMETS data set is very current (until 2010) and includes detailed information such as the patent assignee or the firm to which the patent has been assigned, the dates on which the patent application was filed, and the U.S. patent technical class to which it was assigned. For our purposes, the COMETS database is very useful because it includes inventor names and locations (including the name of city and state), which greatly facilitated our data collection efforts. We collected 24,724 patents granted to the firms in our sample during the study period.

From these patents, we generated a list of inventors and extracted the detailed names and location information from COMETS. Because the USPTO patent database sometimes made errors on the inventor names, for example John Smith as written as Jhon Smith or adding/missing a middle name, we followed Corredoira and Rosenkopf (2010) in their detailed approach to cleaning inventor names. This process yielded 22,387 unique inventors in our sample.

Dependent Variable

This study examines how human capital characteristics of the inventor team affect the firm's decision to maintain or abandon patents. The private value of a patent is best evaluated at the time of patent renewal (Harhoff et al., 1999; Harhoff et al., 2003; Pakes, 1986). We chose data on patent renewal as the proxy of whether the firm considers a specific patent valuable. A patent has sufficient private value to the firm when it meets the cutoff criterion of renewal, and therefore the variable we created is binary.

We collected data on patent renewal from the *USPTO Patent Gazette*, a weekly publication that lists expired patents. To correspond with our data set of patents granted between 1990 and 2004, we collected patent expiration data between 1994 and 2008. We focused on the patents that were not renewed in the fourth year. The expiration decision on a patent after a short 4-year period provides a conservative test indicating that the firm is convinced that there is not much value in the expired patent. The dependent variable is a binary variable to indicate whether a patent is renewed (*renewal* = 1) or not renewed (*renewal* = 0). In our data set, 3,519 patents (out of 24,724 patents) were not renewed at the fourth year, representing about 14% of patents in our sample.

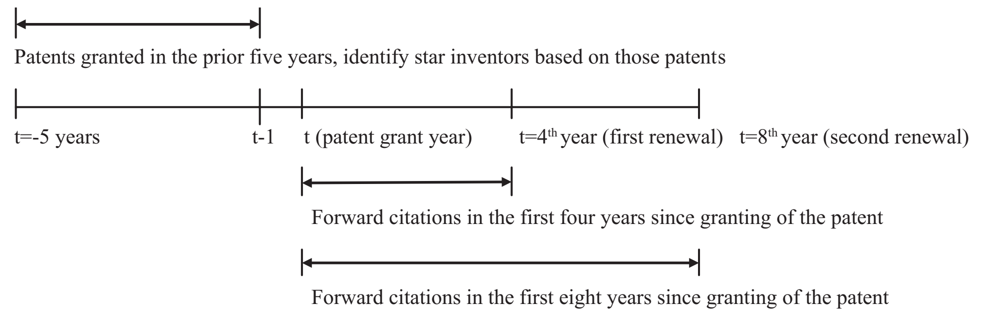
Independent Variables

Having stars. Higher human capital of inventors, as we suggested, increases the private value of patents, particularly when star inventors are involved. We generated a dummy variable to code those patents where at least one inventor has been identified as a star inventor (*having stars* = 1) or none of the inventors is a star (*having stars* = 0).

We identified star inventors using the following steps. First, we calculated the number of patent citations that accrue to the patents in the prior 5 years under the names of inventors who participated in the patent inventions. For patent inventors who obtained patents in the year t, we found those patents obtained by the same inventors from the year t-5 to year t-1. Then we counted the citations received by those patents in the first 5 years since the granting year of the patents and calculated the number of citations to all inventors who have participated in creating that patent. Next we aggregated the citations received by each patent to individual inventors because many inventors were involved in more than one patent during that 5-year period and it was the individual inventors' patenting performance in which we were interested. In doing so, we made certain that patent citations used to identify star inventors, which were citations to the patents from year t-5 to year t-1, would not interfere with patent citations (citing patents granted in year t) that would be used to predict patent renewal. To some extent, the identification of star inventors would attest to their prior success and track records of obtaining breakthrough inventions, which have been established 4 years before their patents were considered for renewal or expiration. Figure 1 illustrates how we created the temporal precedence of our independent variables and enhanced the causality of our predictions.

Among more than 22,000 inventors, the average number of patent citations under an inventor is about 67 and the standard deviation is 173. We followed prior research (Hess & Rothaermel, 2011) and identified 544 star inventors with patent citations over three standard deviations above the mean, which would be 585 citations. These individuals represented only 2.4% of inventors in the sample. We expect that having star inventors on the invention team would increase the chance of patent renewal.

Figure 1
Star Inventors, Identification Based on Patents in Prior 5 Years, Forward Citations, and Patent Renewal Time Period



The number of coinventors. This variable measures the number of coinventors on a patent. Prior research has shown that more inventors on the team would increase the complementarity (Palomeras & Melero, 2010) and social interactions in a complex web of relationship (Hoetker & Agarwal, 2007). We expect that more coinventors would increase the chance of patent renewal.

Multiple locations of coinventors. We generated a dummy variable to code those cases when inventors are not located together (*multiple locations* = 1) and when inventors are colocated (*multiple locations* = 0). When inventors from different locations collaborate on patents, such collaboration indicates a higher level of complementary knowledge pooled from different locations (Lahiri, 2010). Following prior research (Lahiri, 2010), we consider inventors colocated when the locations are within the same U.S. state or in the same country when inventors are outside the United States. We expect that a patent created by inventors at multiple locations would more likely be renewed.

Interaction Variable

Number of coinventors × having star inventors. Hypothesis 4 suggests that team size would positively interact with human capital of inventors. We mean centered the number of coinventors and the dummy variable of having star inventors, and then generated a product of these two variables.

Control Variable

International location. Patents created at international locations but granted in the U.S. patent system represent some knowledge the firm deems important as it has spent extra money in obtaining patents across national borders (Pakes, 1986). We created a dummy variable to indicate whether inventors of a patent are all at international locations (*international location* = 1) or not (*international location* = 0). When a U.S. pharmaceutical firm filed a patent created by purely international inventors, it shows that the patent has some extra value and that it is worthwhile for the firm to maintain the ownership of knowledge represented in that patent. We expect that the international location of inventors will increase the chance of patent renewal.

Forward citations. A patent's technological significance can influence the decision of patent renewal (Harhoff et al., 2003; Liu et al., 2008). A patent of higher technological significance is more likely to be renewed because its underlying knowledge can be more influential. We followed the norms of innovation research that a forward citation is regarded as evidence that the citing patent embodies some knowledge from the cited patent (Ahuja & Katila, 2001; Trajtenberg, 1990). One additional advantage of the COMETS data set is that it is current until 2010. This wider time span of the COMETS data set allowed us to deal with the citation truncation problem, that is, that older patents tend to receive more citations than newer ones regardless of their technological merits (see Hall, Jaffe, & Trajtenberg, 2001, for more details). We used a 6-year time window since the application year of each patent to record the number of citations received by the focal patent (Lahiri, 2010). In so doing, every patent has the same time window to demonstrate its technological significance so that the truncation issue would not interfere with our analyses. We expected that more forward citations would increase the chance of patent renewal.

Backward citations. Prior research also indicates that the number of backward citations is related to patent renewal (Moore, 2005). Patents that cite few prior-art patents are likely to draw upon a narrower body of knowledge, and the knowledge recombination in creating those patents is less likely to generate knowledge of higher value. We counted the number of backward citations and expect that more backward citations will increase the chance of patent renewal.

Claims. A patent's claims establish the boundary of knowledge in the patents and often constitute a legal basis of the firm to initiate lawsuits if the claims are violated (Moore, 2005). More claims broaden the scope of protection. We expect that more claims increase the chance that the firm will renew the patent.

Firm size. We used the log value of the number of employees as a proxy for firm size. A larger firm often attaches less importance to one particular patent whereas a smaller firm holds its patents more dearly. We expect that patents from a bigger firm are less likely to be renewed.

R&D intensity. We used this variable to control for the relative input of the firm into its R&D. We expect more R&D intensity will increase the chance of patent renewal. We divided the firm's R&D expenses by its sales and took the log value to control for the skewness of data.

We included dummies for different years, different firms, and different technological classes of patents to account for unexplained heterogeneity. There were year dummies from 1991 to 2004 with 1990 as the base year and not included in the regression analysis.

Model

Our study has over 24,000 patents from the U.S. pharmaceutical industry as the unit of analysis, and the focus is on whether human capital characteristics of inventors affect patent renewal. Since the dependent variable is a binary variable, we chose logit regression as the estimation method (Liu et al., 2008; Moore, 2005). The equation is given as

$$P\left(y_i = 1 \mid x_i\right) = \frac{\exp(x_i^{'}\beta)}{1+\exp(x_i^{'}\beta)},$$

where β is the vector of coefficients to be estimated. We used Stata 11 to execute the analyses. Due to missing data, the analyses used a sample of 19,092 patents.

Results

Table 1 presents descriptive statistics and correlations. All bivariate correlations are below the recommended 0.70 threshold. To assess the threat of multicollinearity, we calculated the variance inflation factors (VIFs) for each coefficient. The maximum estimated VIF was 1.61, well below the recommended ceiling of 10 (Cohen, Cohen, West, & Aiken, 2003).

Table 2 presents the logit regression results. We first estimated a baseline model using control variables and dummies. Next, we added the main effects from three hypotheses. We last added the interaction effect in the complete model. In all models, each subsequent model represents a significant improvement over the respective baseline models ($p < .01$ or higher). Model 1 comprises control variables only. Most coefficients are significant and in directions as predicted. The results show that patents are more likely to be renewed when created by purely international inventors, having more forward and backward citations, and having more claims; patents from a bigger firm, by contrast, are less likely to be renewed.

Hypothesis 1 suggests that having star inventors on the inventor team will increase the chance of patent renewal. This hypothesis is supported in Model 2. The coefficient of the variable is positive, as we predicted, and significant at the $p < .001$ level. Hypothesis 2 predicts that more coinventors will increase the chance of patent renewal. This hypothesis is supported in Model 3 as the coefficient of the number of coinventors is positive and significant ($p < .001$). Hypothesis 3 posits that if inventors are dispersed in multiple locations, the patent will be more likely to be renewed. This hypothesis is also supported in Model 4 as the coefficient for multilocation is positive and significant ($p < .001$). The results remain the same in Model 5, which includes all three main effect variables.

Hypothesis 4 suggests that when more coinventors work with star inventors, the patent is more likely to be renewed. This hypothesis is supported in Model 6, as the coefficient of the interaction term is positive and significant ($p < .05$) level. This result suggests that having more coinventors amplifies the effects of star inventors, probably because their existence strengthens the diffusion and embeddedness of the patented knowledge in the firm's social community. We illustrate this interaction effect in Figure 2. Because logit models use a logarithm function, the curves are both curvilinear (Hoetker, 2007). When there is no star on the invention team, an increase of the number of coinventors from 1 (1 standard deviation below the mean) to 5.5 (1 standard deviation above the mean) would increase the probability of patent renewal from 87.5% to 89.4%. In comparison, the increase of patent renewal probability is much larger when there are stars on the team. The same increase of the number of coinventors from 1 to 5.5 would increase the probability of patent renewal much more significantly, as shown in Figure 2, from 93.5% to 98.0%.

Table 1
Descriptive Statistics and Correlations

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Renewal	0.85	0.35									
2. Number of coinventors	3.25	2.27	–.02*								
3. Multilocations	0.32	0.47	.03***	.36***							
4. Having stars	0.26	0.44	.06***	.13***	.04***						
5. International locations	0.15	0.36	–.10***	.01	–.22***	–.06***					
6. Forward citations	5.23	9.10	.12***	–.01	.02***	.23***	–.07***				
7. Backward citations	10.73	20.36	.09***	.05***	.04***	.10***	–.11***	.20***			
8. Claims	16.66	17	.07***	.07***	.05***	.09***	–.06***	.12***	.08***		
9. Firm size	2.98	1.58	–.15***	.10***	.02**	–.10***	.20***	.02***	–.03***	–.15***	
10. R&D intensity	0.35	0.66	.09***	–.01*	–.009	.11***	–.12***	–.00	.04***	.18***	–.59***

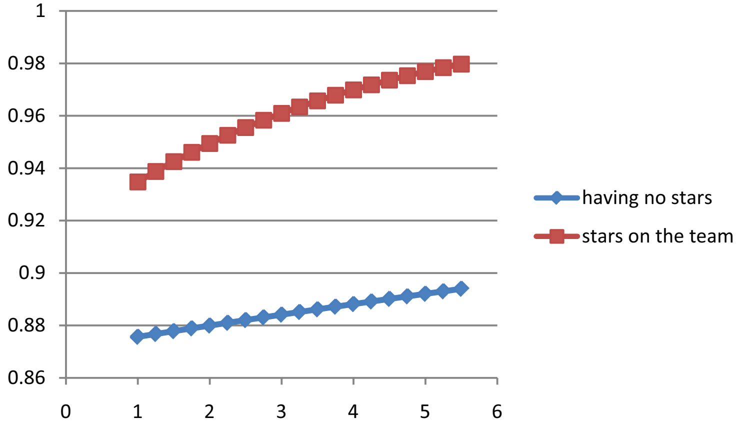
*$p < .05$, two-tailed.
**$p < .01$, two-tailed.
***$p < .001$, two-tailed.

Table 2
Logit Regression on the Likelihood of Fourth-Year Patent Renewal

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Having stars		0.65*** (0.19)			0.60*** (0.19)	0.48** (0.19)
Number of coinventors			0.04*** (0.01)		0.03* (0.01)	0.04** (0.01)
Multiple locations				0.17*** (0.05)	0.11* (0.05)	0.11* (0.05)
Stars × coinventors						0.23* (0.10)
International locations	0.15* (0.06)	0.14* (0.06)	0.15* (0.07)	0.21** (0.07)	0.18** (0.07)	0.18** (0.07)
Forward citations	0.06*** (0.005)	0.06*** (0.01)	0.06*** (0.005)	0.06*** (0.005)	0.06*** (0.005)	0.06*** (0.005)
Backward citations	0.01*** (0.003)	0.01*** (0.003)	0.01*** (0.003)	0.01*** (0.003)	0.01*** (0.003)	0.01*** (0.003)
Claims	0.005* (0.002)	0.004* (0.002)	0.004* (0.002)	0.004* (0.002)	0.004* (0.002)	0.004* (0.002)
Firm size	–0.60*** (0.15)	–0.63*** (0.15)	–0.65*** (0.15)	–0.62*** (0.15)	–0.65*** (0.15)	–0.65*** (0.15)
R&D intensity	0.14 (0.12)	0.001 (0.0004)	0.001 (0.0004)	0.001 (0.0004)	0.001 (0.0004)	0.001 (0.0004)
Constant	3.03** (1.16)	3.31** (1.13)	3.27** (1.13)	3.45** (1.13)	3.35** (1.13)	3.31** (1.13)
Class dummies	Included	Included	Included	Included	Included	Included
No. of observations	19,080	19,080	19,080	19,080	19,080	19,080
χ^2	3335.16***	3349.36***	3349.71***	3346.88***	3365.83***	3371.75***
$\Delta\chi^2$		14.2***	14.55***	14.72***	30.67***	5.92*

Note: Values in parentheses are standard errors.
*$p < .05$, two-tailed.
**$p < .01$, two-tailed.
***$p < .001$, two-tailed.

Figure 2
Interaction Effects of Coinventors and Having Star Inventors on Patent Renewal



Robustness Check

In order to enhance the validity of our study, we conducted a robustness check with a different patent renewal window—the eighth-year window instead of the fourth-year window.[1] Doing so would allow more citations to accumulate in a longer time window, and the decisions made by the firms are more likely to be influenced by variables we describe in the study. We also included those patents not renewed at the fourth year to be a part of the eighth-year nonrenewal patents since by the eighth year those patents were not renewed anyway. We extended the window of observing forward citations from a 6-year window to an 8-year window so that the eighth-year renewal decision could more accurately reflect the citations that have accrued to the patents. One consequence of doing so is that we had to delete those patents granted in 2004 because our patent database could go only as far as 2010. The eighth-year citation window, counting back 8 years from 2010, could reach only 2003, and we had to drop patents granted in 2004. The sample size decreased slightly to 19,009 patents. We report the results in Table 3.

Most results remain consistent with our prior findings. Hypotheses 1, 2, and 3 all receive significant support, showing that having stars on the team, having a larger inventor team, and having intraorganizational linkages enhance the chances of patent renewal. The only change concerns the interaction term that predicts Hypothesis 4. Although it is still positive as we predicted, it is not significant.

Discussion

In knowledge-intensive industries such as the U.S. pharmaceutical industry, inventors' human capital lays the microfoundation for the firm's competitive advantage. Inventors create intellectual assets such as patents, and their human capital underlies those patents they have created. Since inventors are able to move and take away their human capital, one of the ways a firm preserves and protects the value created by inventors' human capital is to

Table 3
Logit Regression on the Likelihood of Eighth-Year Patent Renewal

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Having stars		0.50*** (0.12)			0.46*** (0.12)	0.41*** (0.13)
Number of coinventors			0.04*** (0.01)		0.03** (0.01)	0.03** (0.01)
Multiple locations				0.16*** (0.05)	0.11* (0.05)	0.11* (0.05)
Stars × coinventors						0.09 (0.06)
International locations	0.21*** (0.06)	0.22*** (0.06)	0.22*** (0.06)	0.28*** (0.06)	0.25*** (0.06)	0.25*** (0.06)
Forward citations (8-year window)	0.05*** (0.004)	0.04*** (0.003)	0.04*** (0.003)	0.04*** (0.003)	0.04*** (0.003)	0.04*** (0.003)
Backward citations	0.02*** (0.002)	0.01*** (0.002)	0.01*** (0.002)	0.01*** (0.002)	0.01*** (0.002)	0.01*** (0.002)
Claims	0.005** (0.002)	0.003* (0.001)	0.003* (0.001)	0.003* (0.0015)	0.003* (0.0015)	0.003* (0.0015)
Firm size	–0.94*** (0.14)	–0.94*** (0.12)	–0.95*** (0.12)	–0.92*** (0.12)	–0.94*** (0.15)	–0.95*** (0.15)
R&D intensity	0.0001 (0.0004)	0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)
Constant	3.09** (1.05)	1.11 (1.34)	1.09 (1.34)	1.31 (1.34)	1.23 (1.34)	1.21 (1.34)
Class dummies	Included	Included	Included	Included	Included	Included
No. of observations	19,009	19,009	19,009	19,009	19,009	19,009
χ^2	4123.63***	5102.64***	5103.11***	5100.13***	5124.25***	5127.01***
$\Delta\chi^2$		979.01***	979.48***	976.5***	1000.62***	2.76

Note: Values in parentheses are standard errors.
*$p < .05$, two-tailed.
**$p < .01$, two-tailed.
***$p < .001$, two-tailed.

preserve the value of patents. Patents have to be valuable enough, at least of sufficient private value to the firm, in order to be renewed. Our study extends prior research on human capital and shows that human capital characteristics of inventors can indeed affect patent renewal decisions. We find that the firm is more likely to renew some selected patents where inventors' human capital possesses certain characteristics.

The results show that having star inventors on the inventor team significantly impact patent renewal. Patents invented by star inventors seem to have been favored in patent renewal. The firm may therefore differentiate the private value of patents based on who have invented them. This finding echoes research on star inventors in the context of patent citations or publication output (Hess & Rothaermel, 2011; Zucker et al., 1998). Star inventors often have phenomenal human capital, and their knowledge defines the frontiers of research (Azoulay et al., 2010). Star inventors also contribute to knowledge creation when their tacit knowledge can be spilled over or transferred via learning by collaborators (Zucker et al., 1998). Star inventors provide signals of "quality" to decision makers such as managers or legal attorneys, who are making patent renewal decisions to preserve economic value from patents. Within a portfolio of patents to be renewed, managers or legal attorneys may have limited time or information to make fully informed decisions, a situation where the status of star inventors provides useful cues to their decision making.

Furthermore, our results show that human capital of star inventors can be more important when their presence is coupled with a larger team of inventors. This finding echoes insights from Blyler and Coff (2003: 679), who posited that human capital, properly coupled with social characteristics, can be even more useful. A proper social and organizational context is instrumental to fully leverage star inventors' human capital. This finding of interaction between the size of the inventor team and human capital of inventors confirms the importance of such coupling. The firm would benefit from star inventors not only through their direct contributions, but also through knowledge spillover via coinventors. More collaborators help to leverage the human capital of star inventors (Hitt et al., 2001; Sirmon et al., 2007). Considering the fact that star inventors are also highly mobile or at least potentially highly mobile (Campbell, Coff, et al., 2012; Coff, 1999), the firm's interests would be better protected from threats of value appropriation if the patented knowledge is highly socially embedded.

Our findings regarding complementarity effects of collaborator characteristics are also important and interesting. The complementary knowledge from coinventors would make value appropriation more difficult, either by individual inventors or by competitors that seek to steal away some inventors. While individual inventors may be easy to hire away, stealing a whole team or hiring inventors from multiple locations would be more difficult (Campbell, Coff, et al., 2012; Palomeras & Melero, 2010). A firm would be more capable to preserve and protect value from its patents, either when inventors pool together their specialized knowledge or when some inventors' knowledge can be location specific or sticky. Complementary knowledge within multiple inventors and locations strengthens the firm's position of value protection, just like the effects of complementary assets on value protection and capture (Teece, 1986). Indeed, while individual inventors may seek to leverage their individual-based knowledge at a new employer, team-based and socially coupled knowledge can be very difficult to replicate (Hoetker & Agarwal, 2007).

This study makes a number of contributions to the literature. First, it contributes to the human capital literature by linking human capital to value preservation and value protection of intellectual assets, a novel theoretical direction for human capital literature. Prior research on human capital has established the connection between human capital and value creation such as generating innovation output (Rothaermel & Hess, 2007; Subramaniam & Youndt, 2005). Our study extends prior research and explores effects of human capital after value has already been created and when the firm needs to decide to preserve and protect value from patents. As creators of patents, inventors contribute significantly to the value of patents because of their valuable human capital. Furthermore, inventors' human capital not influences only value creation in innovation but also value protection and preservation of patents.

Second, the study highlights the importance of social and organizational factors that surround human capital. Like prior research that emphasizes the importance of social and organizational context (Hoetker & Agarwal, 2007; Subramaniam & Youndt, 2005), we also highlight how human capital works in conjunction with organizational characteristics. In addition, this study draws our attention to complementarity among inventors in terms of inventor team size and geographical dispersion. Building on recent research on human capital (Campbell, Coff, et al., 2012), we suggest that isolating mechanisms of competitive advantage may lie in complementarity among inventors. Complementary characteristics of how inventors are organized and coordinated within the inventor team would increase the use value of the knowledge created by those inventors and may lower the exchange value, which in turn contributes to value protection by the firm.

Third, the study contributes to patent renewal research by considering inventors' human capital as a novel solution to patent renewal issues. Patent renewal research has mostly focused on technological determinants of patent value and largely ignored human-based characteristics (Moore, 2005; Pakes, 1986). Some research has suggested that the management of intellectual assets such as patents may follow real options logic where managers consider the net present value of patents plus the option value of holding or abandoning patents (McGrath & Nerkar, 2004). This study goes beyond examining technological drivers of patent value or option value, and instead focuses on the more behavioral aspect of patent renewal. This study makes a novel connection between patent renewal research and human capital literature and shows that inventor-based information can be a good indicator of patent value.

There are several avenues for future research to extend the findings of this study. First, future research may introduce more and different notions of human capital. Limited by data availability and the scope of the study, our study differentiates star inventors from nonstar inventors only based on their past patenting success. Future research may examine other dimensions of inventors' human capital, such as their education, tenure at the firm, prior employment experiences, or technological specialization. Second, our study uses patent data, and future research may benefit from some other data such as at the project level. This is particularly relevant to issues of knowledge transfer among inventors since some inventors may be simultaneously engaged in multiple projects, like engineers at the industrial design firm IDEO (Sutton & Hargadon, 1996). Knowledge transfer therefore may happen not only from person to person, but also from one project to another, further diffusing human capital of those star inventors. Third, future research might more specifically investigate how a firm's internal structural characteristics contextualize inventors' human capital, for example, the extent to which the firm's inventors are structurally integrated or differentiated. The intrafirm characteristics of the firm affect the environment in which inventors collaborate and interact.

Our study has a few limitations related to its research setting. First, our study is only focused on the U.S. pharmaceutical industry, and the interpretations of our findings may be limited by the idiosyncrasies associated with this particular industry. Current research on star employees has expanded to other industries such as service industries (Campbell, Granco, et al., 2012; Groysberg & Lee, 2009). It remains to be explored whether knowledge creation and diffusion mechanisms differ in other industries and how those different contexts would affect the role of key employees who are equivalent to star inventors. Second, our study utilizes patent data to construct variables and to identify star inventors. While patent data provide benefits for research exploring inventions and knowledge, future research could strengthen this interesting line of research by incorporating other knowledge-related data such as academic publications. Third, due to the limited data we have, we were not able to explore whether some alternative explanations may explain the value of patents. For example, it is possible that the firm has allocated more resources including more inventors and inventors at multiple locations to particular projects to ensure the success of the projects.[2] Such projects may possibly generate inventions and patents that are particularly valuable to the firm. While such possibilities are certainly interesting, we are limited by the scope of our study and leave such possibilities to future research to explore.

Conclusion

Human capital is a key component of a firm's microfoundation that contributes to its competitive advantage (Barney & Wright, 1998; Coff, 1999; Hitt et al., 2001; Ployhart & Moliterno, 2011). We contribute to the emerging literature on strategic human capital (Campbell, Coff, et al., 2012; Coff, 1999; Ployhart & Moliterno, 2011) by emphasizing the importance of inventors' human capital to value preservation and value protection of patents. Within the specific context of patent renewal by pharmaceutical firms, we show that human capital of inventors as well as complementary characteristics of the inventor team jointly impact decisions of patent renewal.

Notes

1. I thank an anonymous reviewer for suggesting this robustness check.
2. I thank an anonymous reviewer for suggesting this possibility.

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