Inventor knowledge recombination behaviors in a pharmaceutical merger: The role of intra-firm networks

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\begin{abstract}
We study firms' abilities to increase the generative appropriability of their knowledge by studying the knowledge recombination patterns of inventors in the context of a merger between two equally sized pharmaceutical firms. Specifically, we study inventors' choices to recombine knowledge originating in the firm with which they merge. We hypothesize that mergers focus inventors' attention to units of knowledge originating in the other firm and that therefore, inventors will choose to recombine more of this knowledge, which exists in their intra-firm network, following a merger. We also hypothesize that inventors vary in terms of their recombination choices following a merger. We explore these differences by linking inventors' network positions with their abilities and motivations to recombine knowledge originating in the other firm. Specifically, we hypothesize an inverted-U shaped relationship between centrality and knowledge recombination from the other firm and a linear relationship between brokerage and knowledge recombination from the other firm. We test our hypotheses using patent data from the merger between Bristol-Myers and Squibb and find support for our hypotheses. The paper contributes to knowledge recombination research by exploring changes in knowledge recombination dynamics following a merger and by understanding how mergers affect firms' generative research trajectories. Practically, we suggest that managers should identify and nurture certain types of inventors following a merger to be able to better leverage the knowledge bases of merging firms.
\end{abstract}

\section*{Introduction}

Knowledge is a critical resource for achieving competitive advantage (Ahuja, 2000a; Argote, 1999; Grant, 1996; Winter 1987). Ahuja \textit{et al.} (2013) explained that firms use their knowledge capabilities to generate inventions that allow them to appropriate what they termed 'primary' value by creating immediate value for their customers and 'generative' value by using their knowledge as a basis for creating new knowledge in the future. Thus, the value of knowledge may increase over time as firms learn new and different ways of recombining it. In this context, Ahuja \textit{et al.} highlighted the importance of understanding the mechanisms that allow firms to use their present knowledge as a foundation for future knowledge, what they termed generative appropriability (GA). Ahuja \textit{et al.} offered an important foundation for understanding the GA concept by outlining ways in which firms enhance the utilization of their extant knowledge and learn to recombine knowledge in new ways and in an ongoing manner. Interestingly, Ahuja \textit{et al.} did not link GA to the mergers and acquisitions (MA) context even though mergers are events motivated by the desire to maximize firms' abilities.

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https://doi.org/10.1016/j.lrp.2018.03.005

Available online 05 April 2018
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to recombine knowledge in new ways and to do so over a long time horizon (c.f. Graebner et al., 2017; Halebian et al., 2009; Haspeslagh and Jamison, 1991). This is particularly true for R&D motivated mergers. Here, we argue that such mergers are a context for which the GA concept is central and extend Ahuja et al.’s ideas toward understanding the generative aspects of mergers.

More specifically, mergers are events that have both short- and long-term goals. In the short-term, firms hope to exploit the array of capabilities each firm has, such as marketing, production, or supply chain, in a way that creates synergies and increases efficiencies (Haspeslagh and Jamison, 1991; Puranam et al., 2003, 2006; Schweizer, 2005). In the long-term, firms seek to build future knowledge by merging knowledge bases in a way that takes distinct knowledge bases and recombines them in non-obvious ways (Haspeslagh and Jamison, 1991). This long-term orientation aligns well with Ahuja et al.’s (2013) definition of GA as a “firm’s effectiveness in capturing the greatest share of future inventions spawned by its existing inventions”.

We submit that a fundamental approach to understanding how firms work to recombine distinct knowledge bases is to conduct an examination of inventors’ choices in the context of their knowledge recombination activities (Aalbers et al., 2013; Reinholdt et al., 2011). To situate our examination of inventors’ choices, we conceptualize organizational knowledge as units of knowledge residing in an intra-firm inventor network (Nerkar and Paruchuri, 2005; Paruchuri and Eisenman, 2012) and we conceptualize recombination as inventors’ choices regarding which units of knowledge to recombine. We then focus on understanding how mergers may affect inventors’ recombination activities and suggest that mergers act as attention focusing events that draw the attention of the inventors to units of knowledge originally generated by the other firm that reside in their network (Paruchuri and Eisenman, 2012). This increased salience, we posit, would lead to increased recombination of the other firm’s knowledge in the post-merger period compared to pre-merger period.

Importantly, inventors vary in terms of their recombination choices following a merger. We explore these differences by linking inventors’ network positions with their abilities and motivations to recombine knowledge originating in the other firm. We understand these differences in the context of the inventors’ centrality and the extent to which they have networks that are rich in structural holes. In so doing, our paper draws on an established and growing body of work that links individual actors’ network positions to organizational level outcomes (Grigoriou and Rotheaermel, 2014; Lazega et al., 2006; Nerkar and Paruchuri, 2005; Paruchuri and Eisenman, 2012; Rotolo and Messeni Petruzzelli, 2013).

In what follows, we begin with explaining why R&D motivated mergers are useful settings for expanding our understanding of GA and emphasize the importance of autonomy as an integration mechanism in these settings. In a following section, we argue that these mergers are events that focus inventors’ attention to the knowledge generated by the other firm. Therefore, we hypothesize, inventors are more likely to use the knowledge generated by the other firm following a merger. The next section extends this idea by theorizing differences in inventors’ abilities and motivations to recombine the knowledge of the other firm. We then develop two hypotheses highlighting the relevance of inventors’ positions in their intra-firm knowledge networks to their abilities and motivations to recombine knowledge originating in the other firm. A next section describes the empirical context and methodology employed for examining the hypothesized relationships. We follow with our results and end the paper highlighting our contributions. More generally, we apply network-based concepts to understand knowledge recombination patterns following a merger and extend an array of work examining the relationship among structural positions in the organizational network and inventors’ differences in the context of their abilities and motivations to recombine knowledge. We do so to advance recent work on the concept of GA and examine its usefulness in the context of MA. Practically, our paper provides insights for managing knowledge leverage and integration processes by identifying which inventors are likely to recombine the knowledge generated by the firms with which they have merged.

**Generative appropriability and R&D motivated mergers**

Firms often engage in MA to obtain knowledge (Hagedoorn and Duysters, 2002; Puranam and Srikanth, 2007; Ranft and Lord, 2002). While the desire to acquire knowledge can pertain to a variety of contexts, such as market knowledge or operational knowledge, our interest in the dynamics of GA turns our focus to settings in which firms of relatively equal size merge to obtain R&D and do so while maintaining the autonomy of the research laboratories. To explain, R&D is conducted by inventors working in research laboratories. Following a merger, these laboratories are not geographically displaced and inventors’ work remains relatively autonomous in the context of the operational integration following the merger (Angwin and Meadows, 2015; Schweizer, 2005). Arguably, the geographical distance and the relative autonomy suggest that generating useful reorganizations between the knowledge bases residing in each lab is not obvious and requires a long-term orientation and as such, aligns with our interest in understanding GA. More generally, researchers linked the significance of maintaining the autonomy of pre-merger divisions to the extent to which the organization can absorb the tacit and socially complex knowledge of the other firm (Angwin and Meadows, 2015; Haspeslagh and Jamison, 1991).

Additionally, we perceive R&D motivated mergers that maintain the autonomy of research labs as useful settings for exploring the GA concept because knowledge recombination activities in these settings are less likely to be affected by the typical disruptions that characterize integration processes following acquisitions. Indeed, researchers agree that post-merger integration affects the extent to which firms can leverage knowledge successfully (Angwin and Meadows, 2015; Graebner, 2004; Haspeslagh and Jamison, 1991; Kapoor and Lim, 2007; Zaheer et al., 2013). But, although MA are motivated by firms’ desires to leverage knowledge without destroying their underlying capabilities (Ernst and Vitt, 2000; Paruchuri et al., 2006; Very et al., 1997), integrating merging firms is often wrought with problems. For example, researchers found that MA can increase turnover of inventors who perceive the MA as harming them professionally or socially (Paruchuri et al., 2006), that cultural differences among merging firms often have a negative impact on knowledge leverage (Junni and Sarala, 2013; c.f., Sarala and Vaara, 2010), and more generally, that MA are disruptive as
they affect organizational members’ abilities to identify with the new organizational entity (Empson, 2001).

We suggest that mergers that maintain the autonomy of research labs potentially minimize some of these hindrances that characterize post-merger settings, often studied in the context of acquisitions that are characterized by having a clear power differential in which a large firm purchases and absorbs a smaller one. Work on acquisitions shows that inventors’ and star researchers’ departure may prevent merging firms from benefiting from the knowledge these individuals possess. To the extent that such departures are motivated by disruption to their routines (Paruchuri et al., 2006; Ranft and Lord, 2002), a merger that maintains the autonomy of research labs, such as often evident in the pharmaceutical industry, may minimize these dynamics because inventors continue their stream of work in a relatively unchanged setting in which changes to processes are not readily apparent. The autonomy of R&D laboratories is likely to minimize effects of a cultural clash or identity struggles for similar reasons. Autonomy suggests that the routines within a lab are unlikely to change in the context of a shift in the overall organizational culture and it suggests that the identity of inventors, linked most closely to their work and personal research trajectory, is unlikely to be threatened.

Mergers as attention focusing events

Having established the context of an R&D motivated merger that maintains the autonomy of research labs and its relationship to understanding GA, we turn toward understanding inventors’ knowledge recombination choices in such merger settings. In general, mergers are major events that draw the attention of firm employees. Prior findings show that mergers affect behavior and productivity (e.g., Ernst and Vitt, 2000; Kapoor and Lim, 2007; Paruchuri and Eisenman, 2012; Paruchuri et al., 2006; Sarala and Vaara, 2010; Siegel and Simons, 2010) as well as cognitive states such as identification (Knippenberg et al., 2002) or anxiety (Cartwright and Cooper, 1992; Marks and Mirvis, 2001). Here, we suggest that mergers focus attention in a way that affects inventors’ choices about knowledge recombination.

To explain, the long-term orientation of a merger affects inventors by altering the ways in which they perceive the well-understood and established focus of their firm’s R&D and its future (Ocasio, 2011). More generally, attention focusing events have been found to affect innovation outcomes (Yadav et al., 2007). Building on this, we suggest that mergers are settings that enable inventors to continue their knowledge development trajectories as these exist in their original R&D divisions while also increasing their sensitivity to and awareness of new knowledge assets that can drive the merged firm’s future recombination activities. More specifically, in the absence of formal integration mechanisms, R&D divisions from the original firms become divisions within the combined firm and cease to be external entities vis-à-vis each other. Because the merged entities’ routines are not entirely combined and the divisions remain distinct, the knowledge originating in each firm is neither completely internalized into the newly merged firm nor spread across organizational boundaries (Szulanski, 1996; Ranft and Lord, 2002). Additionally, the geographical distance and relative autonomy generate a context in which each firm’s intra-firm inventor network remains intact (and separate from the other firm’s intra-firm inventor network). At the same time, the merger acts as an attention focusing event and increases inventors’ awareness to the other firm’s scientific records, research reports, and other such documents. This increased awareness allows inventors from each firm to recombine knowledge from the other firm to innovate (Ahuja and Kattila, 2001; Fleming, 2001; Henderson and Cockburn, 1994).

Put differently, inventors work in labs and specialize in their research areas, and research showed that they perform local search, primarily searching within their firms and networks (Paruchuri and Awate, 2017). These research activities likely lead to the generation of inventions that firms appropriate for their primary value. Following a merger, we expect inventors to increase their attention and sensitivity to the knowledge originating in the other firm. Such knowledge may already exist in each firm’s intra-firm inventor network or in the knowledge stocks that flow into their network post-merger. But importantly, while these knowledge stocks may have been present in the network even before the merger, they did not attract particular attention and were similar to all other units of knowledge that reside in the network. However, in the post-merger context, inventors give particular attention to the other firm’s knowledge and the saliency of such knowledge increases the likelihood that it will be recombined more than in the pre-merger period. Therefore, as a baseline hypothesis, we posit that:

**Hypothesis 1.** A firm’s inventors will recombine the other firm’s knowledge to a greater degree after the merger than before the merger.

Knowledge networks and inventors’ abilities and motivations for post-merger knowledge recombination

We build on this baseline hypotheses and extend our idea that inventors will recombine the knowledge of the other firm to a greater extent after the merger by explaining variations in inventors’ post-merger behaviors. Specifically, we theorize that inventors’ abilities and motivations to recombine the knowledge of the other firm are likely to vary. We do so by drawing on the notion of an intra-firm inventor network. Inventors collaborate with one another and the accumulation of these collaborations forms a network in which inventors are embedded and within which they exchange knowledge and ideas (Gulati, 1995; Rotolo and Messeni Petruzzelli, 2013). This understanding is linked to the conceptualization of organizational knowledge as residing in an intra-firm inventor network (Nerkar and Paruchuri, 2005; Paruchuri and Eisenman, 2012). In this context, a large body of work describes the relationship between network characteristics and performance-related outcomes such as innovation (e.g., Reinholdt, et al., 2011; Tsai, 2001). In connection with this tradition, we study inventors’ attempts to recombine the knowledge of the other firm using network concepts.

Specifically, we build on a body of work that examines the relationship between network positions and knowledge recombination using two lenses: inventors’ abilities in terms of recombining knowledge and inventors’ motivations to do so. More specifically,
inventors' different structural positions within their intra-firm knowledge networks affect knowledge recombination because different positions afford different benefits, such as the ability to collect or disseminate knowledge (Brass, 1984; Ibarra, 1993; Tushman, 1977; Tushman and Scanlan, 1981). In this context, scholars argued that creating network ties is considered beneficial but that actors differ in their abilities and motivations to create these ties (Ahuja, 2000b; Tsai, 2001). For example, Junnii and Sarala (2013) argued that processes of knowledge recombination depend on organization members' abilities to absorb knowledge and their motivations to do so. Inventors may have various abilities in terms of skills, competencies or educational backgrounds that affect the ways in which they can access and understand knowledge. And, inventors may be motivated to invest more or less effort in doing so (Aalbers et al., 2013; Gupta and Govindarajan, 2000; Reinhold et al., 2011; Szulanski, 1996).

In what follows, we argue that inventors' abilities and motivations to recombine the other firm's knowledge vary as a function of their positions in their intra-firm knowledge networks. Specifically, we hypothesize that inventors' centrality and the extent to which their networks are rich in structural holes, what we term brokerage, at the time of the merger, influence their post-merger recombination of the other firm's knowledge.

Inventor centrality

As the centrality of inventors increases, their reach within the network increases. So, highly central inventors are able to gather information quickly and widely relative to less central inventors in their firm (Bonacich, 1987; Rotolo and Messeni Petruzzelli, 2013). Indeed, ability has been linked to certain network positions, such as centrality and brokerage, that tend to increase inventors' abilities to access and understand new and diverse knowledge that flows in their networks (Aalbers et al., 2013; Reinhold et al., 2011). Therefore, highly central inventors are in a better position than others to identify and recombine units of knowledge about the other firm's knowledge that resides in their original intra-firm inventor network at the time of the merger. And, highly central inventors are in a better position to identify and recombine units of knowledge about the other firm's knowledge that seep into their original intra-firm network because of interactions with the other firm's scientists after the merger. Thus, the ability to recombine the other firm's knowledge increases as the centrality of Inventors in their original intra-firm network increases (at least until they maximize their absorptive capacity (e.g., Aalbers et al., 2013; Qi Dong et al., 2017; Junnii and Sarala, 2013; Tsai, 2001)).

The motivation of these inventors to recombine the other firm's knowledge, however, decreases as their centrality increases. In general, inventors are highly motivated to maintain their centrality and consider centrality to be related to generating more significant innovations (Qi Dong et al., 2017). In the MA context, central inventors feel threatened by the merger as they are afraid of losing their relative position and other benefits associated with their status (Hambrick and Cannella, 1993; Lubatkin et al., 1999). For example, Paruchuri et al. (2006) found that inventors who had the most local status and influence before an acquisition were most susceptible to integration disruption post acquisition even in the absence of formal integration of R&D divisions. This finding shows that the fear of status loss by itself induces discontent and de-motivates inventors, even when they are not dislocated. In the context of such actual or perceived threats, the motivation to maintain centrality increases.

Potentially, inventors can strategize to maintain centrality by intensifying their focus on their original firms' knowledge base. Following an R&D motivated merger, central inventors are unable to influence the other firm's scientists through cross-division collaborations. So, one way for such central inventors to retain their relative importance after the merger is to build on their original firm's knowledge, which will increase their own importance (Podolny and Stuart, 1995), and to avoid using the other firm's knowledge, which will increase the importance of the other firm's inventors. Furthermore, recombining high amounts of the other firm's knowledge can lead to a shift in the original firm's knowledge base (Cohen and Levinthal, 1990; Zahra and George, 2002), which will decrease inventors' importance in their original firm and in the combined firm. The most central inventors are motivated to prevent this shift.

Conversely, inventors can strategize to maintain centrality by increasing their recombination of the other firm's knowledge, implying their expectations regarding the long-term goals of the merger in the context of generating new knowledge reorganizations by integrating distinct knowledge bases. We expect this approach to appeal to moderately central inventors. Because less central inventors did not have as much status before the merger, they view the merger as offering less threats and more opportunities, for example, opportunities for promotion, in the combined organization. So, moderately central inventors are more motivated to recombine the knowledge of the other firm relative to highly central inventors.

Overall, inventors' choices will reflect combined effects of their abilities and their motivations to recombine knowledge from the other firm. The ability of inventors with low centrality to gather information about the other firms' knowledge is limited. Even though their motivations to recombine might be high, such lack of ability constrains their potential to recombine. Inventors occupying high centrality have greater abilities to recombine the other firms' knowledge. However, their motivations are lower resulting in fewer recombinations of the other firm's knowledge. Inventors with intermediate levels of centrality will have both high abilities and high motivations to recombine the other firm's knowledge. Such inventors will recombine the most knowledge from the other firm. Therefore:

**Hypothesis 2.** Inventors' centrality in their original intra-firm knowledge network at the time of the merger is related in an inverted-U shape relation to the amount of post-merger recombination of the other firm's knowledge.

**Inventor brokerage**

The context of a merger draws attention to the other firm's knowledge and makes it salient for recombination activities. Under such conditions, the ability to cull knowledge originating in the other firm, both knowledge that exists in the original intra-firm network at the time of the merger and unique knowledge flowing from the other firm after the merger, gains importance. The skills of
brokers, inventors whose networks are rich in structural holes (Burt, 1992), are useful for sorting out redundancies and identifying unique knowledge. Specifically, brokers connect various parts of their intra-firm inventor network and collect diverse knowledge (Burt, 1992). Thus, these inventors have the ability to identify and access any of the other firm's knowledge residing in their own network. Furthermore, this ability is linearly related to the extent to which the broker's network is rich in structural holes (Reinholt et al., 2011).

The motivation to recombine the other firm's knowledge also increases to the extent that inventors have a richer network in terms of structural holes. First, such recombination of the other firm's knowledge enhances their status. Specifically, brokers are known within their networks for culling unique knowledge from vast amounts of redundant information (Burt, 1992, 1997). To retain such increased status following a merger, these inventors collect the knowledge of the other firm that flows in diverse parts of their own network. Second, the uncertainty characterizing the merger context also increases brokers' motivations to search distant information (Stea and Pedersen, 2017). Third, brokers' relatively higher ability to make sense of the knowledge of the other firm increases their motivation to recombine it (Reinholt et al., 2011).

Taken together, because both the ability and the motivation to recombine the other firm's knowledge following a merger increases to the extent that a broker's network is rich in structural holes, we predict:

**Hypothesis 3.** The extent to which inventors' networks in their original firm at the time of the merger are rich in structural holes is positively related to the amount of their post-merger recombination of the other firm's knowledge.

**Research design and methods**

**Research setting**

We use a merger of two large pharmaceutical firms to examine our hypotheses about knowledge recombination following a merger. Pharmaceutical mergers form a good context to study knowledge networks because of the vast importance given to R&D in this industry (Grabowski and Vernon, 1992; Scott Morton, 2000). This importance is evident from the ratio of R&D expenditures to sales (about 17% in the pharmaceutical industry compared to 5.8% in the electronics industry during the 1980s (Giorgianni, 1997)). Specifically, we focus on the 1989 merger of Bristol-Myers and Squibb, which was dubbed a marriage of equals and created the second largest pharmaceutical firm at that time with combined sales of over $4 billion and R&D expenditures of over $500 million in 1988. These firms were merged to capitalize on the potential complementarities of the research pipeline of each firm as evidenced by the joint statement of the two firms' CEO's, "... this combination will represent a nearly exact fit of the two companies' strategic advantages in research" (Parrott and Skule, 1989). Further, the selection of a merger of two large firms allows us to test our hypotheses as these firms would have a sizeable knowledge network.

To understand the more qualitative aspects of this merger, we read each of the annual reports published during the 1989–1995 period as well as articles in the business press about the merger (we read each article that appeared in the ABI Inform database searching for Bristol-Myers Squibb and merger). Our reading allows us to state that this merger was successful. Sales as well as shareholders' return on equity increased following the merger (Annual Reports; Koberstein, 1995). The merger had important goals in terms of increasing efficiencies in administration, marketing, sales, and operations, but its overarching goal was to capitalize on the complementarities of the pharmaceutical capabilities each individual firm had prior to the merger (Parrott and Skule, 1989; Waldholz, 1989). To this end, both firm executives and the popular press identified several benefits the merger would have on the research trajectories of the firms. Relatedly, R&D spending increased consistently following the merger (Annual Reports; Waldholz, 1989). And although there resulting from the merger, were in the context of the expected efficiencies, these terminations did not affect inventors (Koberstein, 1995; Waldholz, 1990). Lastly, no culture clash or extensive departures were reported as outcomes of this specific merger (Koberstein, 1995; Parrott and Skule, 1989; Winslow and Waldholz, 1989).

Furthermore, in the specific context of inventors' work, the research divisions of Bristol-Myers and Squibb were brought under a new administrative division, Bristol-Myers Squibb Pharmaceutical Research Institute, in 1990 (PR Newswire, 1990). Importantly, the research division of each firm was comprised of multiple labs spread out in numerous geographic locations (Annual Reports). Inventors working in these labs specialized in specific research areas such as oncological or cardiovascular drugs and these areas were non-redundant (Annual Report, 1990). An examination of the inventor locations and collaborations on patents applied during this observation period, as described below, suggests that these research labs remained autonomous until at least the end of the observation period in 1994. Put differently, the integration processes that took place in Bristol-Myers Squibb did not involve combining inventors and co-locating them geographically or merging laboratories. Work in laboratories remained intact while some administrative aspects related to operating laboratories as business units was integrated.

**Sample, dependent variable, and analytical technique**

We use patent data to test hypotheses. Each patent represents a novel, distinct, and discrete piece of new knowledge generated, and has information about its inventors, an application date representing the latest day when the innovation was complete, and a grant date representing the day that the firm acquired legal ownership of the knowledge. Earlier research shows that patents form a good indicator of a firm's technological strength and knowledge in the pharmaceutical industry (Ahuja, 2000a; Ahuja, 2000b; Henderson and Cockburn, 1994; Jaffe et al., 1993; Narin et al., 1987; Silverman, 1999). Patents are also the most important way of protecting intellectual property rights in this industry (Levin et al., 1987). Additionally, patent data provide good historical documentation of research activities in pharmaceutical firms because these firms tend to patent all possible innovations.
Inventor knowledge recombination behaviors in a pharmaceutical merger: The role of intra-firm networks

We collected information from the United States Patents and Trademarks Office (USPTO) website about patents assigned to the two independent firms (Bristol-Myers and Squibb) before the merger and about patents assigned to the combined firm (Bristol-Myers Squibb) after the merger. Specifically, we gathered information about patents assigned to each of the independent firms with application dates between 1975 and 1989 and patents assigned to the combined firm with application dates from 1990 to 1994. The use of application dates suggests that work on these patents evolved after the merger. Note that since the data were collected after 2000, the data capture all the successful patents created during the observation period. The combined firm entered into a merger with another firm containing a large research department at the end of 1994. Because the observations after 1994 are a result of the combination of complicated processes of the first and the second mergers, we stopped the observation at the end of 1994.

One issue with this data was about distinguishing post-merger patents as belonging to one of the pre-merger firms (Bristol-Myers or Squibb). Patents were generated under the same name (Bristol-Myers Squibb) after the merger. Thus, the assignee name on the patent generated post-merger is not useful for distinguishing patents of different pre-merger firms (Bristol-Myers or Squibb). However, as mentioned earlier, research labs were not integrated across firms throughout the end of the observation period. As a result, each patent was generated by inventors who belong to only one of the pre-merger firms. So, using the pre-merger affiliation of inventors on post-merger patents, we were able to assign the post-merger patents to different pre-merger firms. New inventors who appeared after the merger were sorted into one of the pre-merger firms by their co-patenting associations with the known Bristol-Myers or Squibb inventors. Finally, we examined the locations of inventors on these patent applications before and after integration to verify that autonomy was maintained.

Because recombining knowledge from the other firm after a merger is influenced by the inventors’ positions in their original firm’s network at the time of the merger, we compare post-merger recombination across different inventors. In this inventor-level analysis, we examine variation across inventors within a firm. So, the sample consists of all active inventors at the time of the merger. We identified these inventors as those who have patented with either firm in the five-year period preceding the merger. There were a total of 539 active inventors, and we create an observation for each inventor.

The dependent variable for each inventor observation is the amount of knowledge recombined by him/her from the other firm in the five-year period following the merger, i.e., 1990–1994. We measure this as the number of patents of the other firm that were listed in the “prior art” section of the inventor's patents applications during 1990–1994. Listing a patent in the “prior art” implies that the knowledge embedded in the patent was recombined to generate the innovation. As the dependent variable is a count measure, we can use the Poisson family distribution models. However, to take into account the over-dispersion that might exist in the data, we use negative binomial distribution models (Cameron and Trivedi, 1998). Additionally, we included a firm fixed-effects analysis based on pre-merger firms so as to compare recombination of inventors within each pre-merger firm.

The data pose one more issue. Specifically, not all inventors in the sample continued to patent after the merger, and the dependent variable for these inventors is not defined. Of the 539 inventors who patented in the pre-merger period, 219 inventors patented in the post-merger period. One alternative is to assign zero amount of knowledge recombined for inventors who did not patent in the post-merger period. This is not correct because this option does not distinguish between those inventors who patented but did not recombine knowledge from the other firm and those inventors who did not patent at all. The other alternative is to eliminate such inventors from the sample. However, this elimination of inventors who had not patented post-merger might not be random. Specifically, a systematic relationship between the post-merger patenting of inventors and their centrality or level of brokerage or some other characteristic might exist. To take into account any systematic differences between those who continue to patent and those who stop patenting after the merger, we employ the Heckman two-stage type selection models (Heckman, 1976). In these models, the first-stage model, a sample selection model, estimates the probability of inventors continuing to patent post-merger using a Probit model. The dependent variable of this analysis is a dichotomous variable indicating whether an inventor has patented after the merger. From this analysis, we calculate an inverse Mill's ratio, which is included as a predictor in the second-stage negative binomial regression models (see results in the Appendix Table). The statistical significance of the estimated coefficient on the inverse Mill's ratio (often called the selectivity correction) tells us if any selectivity bias is present, with its sign telling us the direction of this bias.

Independent variables

We predict the post-merger recombination of the other firm’s knowledge by inventors using their structural position in their intra-firm inventor network at the time of the merger. We measure this position using the co-patenting information on all patents filed in the five-year window before the merger (i.e., 1985–1989). From the co-patenting network in this window, we calculated each inventor’s centrality and level of brokerage in their original firm's network using UCINET VI (Borgatti et al., 2002) as described below.

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2 Even after this sorting, there were two patents whose inventors did not collaborate with any of the known Bristol-Myers or Squibb inventors or their collaborators. These two patents had four inventors. We have tried different ways of handling them: ignore them, assign them to either Bristol-Myers or Squibb, or assign them randomly to one of the firms. The results were consistent across analyses ignoring them and assigning them randomly to one of the firms. Here, we present results for data ignoring them.

3 This is in line with earlier research which examines the position of actors at the time of the observation with the network formed in earlier years. Moreover, we cannot use co-patenting ties on patents generated during 1990–1994 as independent variables in this analysis because of the timing of these ties and the occurrence of the dependent variable. Specifically, the dependent variable is the amount of recombination during 1990–1994. If we measure inventor's position using the co-patenting ties in the same period, we will, for example, be trying to predict recombination in 1990 by ties that will be formed in 1994.
Inventor centrality

Bonacich power measures the centrality of actors (Bonacich, 1987). The advantage of this measure is that it takes into account the centrality of others connected to the focal inventor (Podolny, 1993; Sorensen and Stuart, 2001). We used the following formula:

\[ c(\alpha, \beta) = \alpha \sum_{k=1}^{\infty} \beta^k R^{k+1} \]

Where \( c(\alpha, \beta) \) is a vector of centrality scores for the inventors, \( \alpha \) is an arbitrary scaling factor, \( \beta \) is a weight, and 1 denotes a column-vector of ones. The magnitude and sign of the variable \( \beta \) determine the weight given to the centrality of inventors connected to the focal inventor in calculating the centrality of the focal inventor. This variable measures degree centrality scaled by \( \alpha \) when \( \beta > 0 \). However, the influence of a focal inventor decreases as the influence of his/her alters increases when \( \beta < 0 \). We set \( \beta \) equal to 3/4 of the reciprocal of the largest Eigen value of X, as is the norm in the networks literature (Podolny, 1993).

Inventor brokerage

We use the efficiency measure of structural holes developed by Burt (1992) and employed a measure from Burt (1992) that uses the ratio of non-redundant contacts to total contacts for a focal inventor as:

\[ \frac{X_j \cdot (1 - \sum_{p=1}^{m} p_{pq} m_{pq})}{C_j} \]

Where \( p_{pq} \) is the proportion of inventor i's ties invested in contact q, \( m_{pq} \) is the marginal strength of the relationship between contact j and contact q, and \( C_j \) is the total number of contacts for inventor j. Higher values on this index reflect inventors whose ego networks are richer in structural holes. If all the co-inventors of an inventor are disconnected from one another, the index takes a value of 1, indicating that none of the inventor's contacts are redundant.

Control variables

We include several variables that might influence recombination choices. First, we include the tenure of the inventor measured as the difference in years between the day of merger and the day of the first patent application of that inventor or 1975 when we started collecting the patent data. Higher tenure could mean high embeddedness within the original firm's network, and hence, lower willingness to recombine knowledge originating from the other firm (Katz, 1982). Second, we include the collaboration patterns of each inventor as controls. The pattern could systematically differ before and after the merger, and could influence the use of the other firm's knowledge (Läberskind et al., 1996). Hence, we include the average number of inventor's collaborators per patent in the five-year period before and five-year period after the merger as control variables. We expect to find a positive relationship between these measures and knowledge recombination because the reach of inventors will be increased by the number of inventors with whom they collaborate. Third, inventors' productivity also influences their use of the other firm's knowledge. So we include the number of patents generated by each inventor in the five-year period before and five-year period after the merger as controls. We expect a positive relationship between this productivity and the amount of knowledge recombined from the other firm.

Fourth, some inventors might be more inwardly focused than others (Allen et al., 1979; Tushman, 1977; Tushman and Scanlan, 1981). To account for this, we include the pre-merger same firm knowledge recombination measure, the number of patents from the inventor's original firm that are listed in the "prior art" section of inventor's patents generated in the five-year period before the merger. Further, we include a lagged dependent variable to account for the inventor's past knowledge recombination from the other firm. We measure it as the number of patents of the other firm that are listed in the "prior art" section of the inventor's patents generated in five-year period before the merger. We also included total pre-merger knowledge recombination measured as the total number of patents listed in the "prior art" section of the inventor's patents generated in the pre-merger five-year period. Fifth, since use of an inventors original firm's knowledge might limit the attention that the inventor could spend on the other firm's knowledge (Simon, 1991), we include the post-merger same firm knowledge recombination as the number of patents of an inventors' firm that are listed in the "prior art" section of inventor's patents generated in the five-year period and the post-merger total knowledge recombination measured as the total number of patents listed in the "prior art" section of inventor's patents generated in the five-year period after the as controls.

Sixth, we include the breadth of inventor's expertise. We measure this as the number of different classes of the inventor's patents as defined by the USPTO classification system. We expect a positive relation between the variable and the amount of knowledge recombined because the potential for recombination increases with the increase in the inventor's breadth of expertise. Seventh, we include the potential recombination base of the other firm as a control. We measure this as the number of patents of the other firm that belong to the inventor's area. Increase in the potential for recombination should increase the amount of recombination. Finally, to account for change in an inventor's relative status following the merger, we compute the percentile ranking of each inventor in their original firm and in the combined firm in terms of their productivity at the time of the merger. We include the difference of their percentile ranking in the combined firm and in their original firm as an additional control variable in the analysis.

Results

To test our baseline hypothesis that the inventors will recombine the knowledge of the other firm more after the merger than before the merger (H1), we performed a t-test on the sample of inventors who patented in the pre-merger and post-merger periods. As
Table 1
Descriptive statistics and simple correlations.

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<td>Breadth of expertise</td>
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<td>0.12</td>
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<td>0.06</td>
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</table>

Notes: all correlations greater than |.13| are significant at p < .05 level.

mentioned earlier, for those inventors that did not patent in the post-merger period, the amount of knowledge recombined, measured in terms of the number of citations to the other firm’s knowledge, is undefined. So, we performed a t-test on the amount of knowledge recombined from the other firm by the 219 inventors who patented in the pre-merger and the post-merger period.

Results show that following the merger, inventors recombined knowledge originating in the other firm to a greater degree relative to the pre-merger period. On average, there are 0.954 more citations of the other firm’s knowledge in the post-merger patent applications relative to the citations of the other firm’s knowledge in the pre-merger patent applications. This difference is statistically significant at p = 0.000 level. This result supports our first hypothesis.

To test variations among these inventors in terms of their post-merger recombination of the other firm’s knowledge, we performed a negative binomial regression analysis. The descriptive statistics and simple bivariate correlations of the variables in this analysis are presented in Table 1, and the regression results are presented in Table 2.

Model 1 of Table 2 includes only the control variables. The selection correction factor is positive and significant implying that there is a selection bias and that inclusion of the correction factor to adjust for this selection bias is appropriate. Additionally, an inventor’s tenure, pre-merger knowledge recombination from the original firm, breadth of expertise and gain in relative status are all positively influencing the amount of knowledge recombined from the other firm; pre-merger collaboration patterns and pre-merger total knowledge recombined are negatively associated with the extent of post-merger knowledge recombined from the other firm.

The results of the specification with inventors’ centrality is presented in Model 2, but the coefficient for centrality is not significant. In Model 3, we include the square term of centrality along with the linear effect of centrality itself. The results show that centrality has an inverted-U shape relation with the extent of recombination of the other firm’s knowledge supporting hypothesis 2. When we examine this curvilinear effect, we find that the amount of recombination increased up to a centrality value of 0.77 but declined for inventors whose centrality is beyond that level.

The results of the specification with inventors’ level of brokerage in presented in Model 4. The coefficient is positive and significant, implying that for higher levels of brokerage, that is for brokers with networks richer in structural holes, the amount of post-merger recombination of the other firm’s knowledge increases. This result supports hypothesis 3. A standard deviation increase in richness in the span of structural holes for an inventor results in a 46.4% (= exp (1.589*0.24)) increase in the amount of other firm’s knowledge recombined by the inventor.

We present the model with linear terms of centrality and brokerage in Model 5. While the brokerage variable is positive and significant, centrality is not significant. But, when we include the full model with linear and quadratic terms of centrality and a linear term of span of brokerage in Model 6, centrality has curvilinear effect and brokerage has a positive effect, supporting hypotheses 2 and 3.

Discussion

This paper advances our understanding of firms’ abilities to increase the generative appropriability of their knowledge by studying the knowledge recombination patterns of inventors in the context of a merger between two similarly sized pharmaceutical firms. Results show that following a merger, inventors recombine more knowledge from the other firm than they did before the merger. Indeed, the merger increases inventors’ attention to the other firm’s knowledge, which increases the actual use of knowledge originating in the other firm in post-merger recombination activities. Beyond this baseline finding, our results differentiate between the
Table 2
Results of negative binomial regression.

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<td>3.328**</td>
<td>2.837**</td>
<td>2.907**</td>
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<td>(0.057)</td>
<td>(0.484)</td>
<td>(0.767)</td>
<td>(0.012)</td>
<td>(0.508)</td>
<td>(0.820)</td>
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<td>1.110**</td>
<td>1.078**</td>
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<td>(0.168)</td>
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<td>−0.109**</td>
<td>−0.114**</td>
<td>−0.133**</td>
<td>−0.112**</td>
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<td>(0.004)</td>
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<td>(0.025)</td>
<td>(0.007)</td>
<td>(0.018)</td>
<td>(0.023)</td>
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<td>0.140</td>
<td>0.117</td>
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<td>−0.011**</td>
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<td>(0.149)</td>
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<td>(0.178)</td>
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<td>0.002**</td>
<td>0.002**</td>
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<tr>
<td>Change in relative position</td>
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<td>0.251**</td>
<td>0.231**</td>
<td>0.262**</td>
<td>0.265**</td>
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<td>(0.011)</td>
<td>(0.024)</td>
<td>(0.017)</td>
<td>(0.003)</td>
<td>(0.012)</td>
</tr>
</tbody>
</table>

Centrality: −0.634 | 0.364 | −0.816 | 0.298 |
| (Centrality)^2: 1.998 | 0.995 | 1.126 | 0.981 |
| Structural holes: 1.589** | 1.704** | 1.818** |
| Log likelihood: −187.3 | −186.9 | −186.2 | −185.5 | −184.8 | −183.7 |

Notes: **: p < .001; *: p < .01; *: p < .05; two-tailed tests; Robust standard errors are in parentheses. Bold variables are variables with theoretical significance.

types of inventors who are more likely to do this recombination. Specifically, moderately central inventors (with a centrality value of 0.77) recombined more knowledge originating from the other firm than either the least or the most central inventors. And, results show that the amount of post-merger recombination of knowledge originating from the other firm increased linearly to the extent that inventors had high levels of brokerage.

Theoretical contributions

The paper contributes to a growing body of work examining how firms work to realize the potential value of their knowledge and addresses Ahuja et al.'s (2013) call for increasing scholars’ understanding of GA by examining knowledge recombination in the context of a merger of equals. As such, our paper connects to research studying the collaboration patterns of inventors to illuminate firms’ knowledge generation and recombination processes as well as the long-term evolution of knowledge trajectories (e.g., Grigoriou and Rothenbel, 2014; Nerkar and Paruchuri, 2005). In this context, our results can be understood as relevant to the suggestion that mergers, having a long-term orientation, are events that affect inventors by altering the ways in which they perceive the well-understood and established focus of their firm’s R&D and its future (Ocasio, 2011). Understanding these processes is important because the choices inventors make with regard to the new knowledge they recombine following a merger affects the path dependent processes of the merged firm's knowledge trajectory. Obviously, such recombinations are realized over longer time horizons. Therefore, we view these R&D motivated mergers contexts as useful for deepening our understanding the underlying dynamics of GA.

In what follows, we specify three additional areas of contribution that advance our ability to understand how mergers relate to firms’ abilities to realize the potential of their knowledge base. First, we work in the tradition of research on microfoundations (Abell et al., 2008) and we link organizational level changes to the behaviors, actions, and choices that take place at the micro level as
manifested by individual inventor’s choices regarding which knowledge to recombine. In particular, we understand inventors’ choices as emanating from their abilities and motivations to access and recombine knowledge that was not invented in their own firm. Here, we build on and extend a body of work that studies knowledge recombination in terms of inventors’ abilities and motivations (Reinholt et al., 2011; Rotolo and Messeni Petruzzelli, 2013).

Furthermore, the paper demonstrates the usefulness of the network concept for exploring inventor choices in the context of the likely abilities and motivations different inventors in different positions have. In this context, the paper speaks to a body of work set to understand organization level outcomes on the basis of understanding network positions and their particular affordances (e.g., Grigoriou and Rothenberg, 2014; Lazega et al., 2006; Nerkar and Paruchuri, 2005; Reinholt et al., 2011) and brings these ideas to furthering our understanding of post-merger knowledge recombination choices (e.g., Allatta and Singh, 2011; Paruchuri and Eisenman, 2012).

Second, the findings in this paper offer implications for research on knowledge recombination in the context of post-merger integration. Haxespilagh and Jemison (1991) termed mergers in which there is little formal integration as “holding” and emphasized the importance of minimizing disruptions related to integration. Here, an important insight derived by our results is that even when research labs maintain their autonomy and in so doing, prevent explicit cross-firm collaborations and operational integration, the pre-merger dynamics of knowledge recombination are different from post-merger dynamics in the two merging firms.

In this context, the study contributes to research examining post-merger integration by exploring the organizational benefits of maintaining autonomy of research labs beyond the studied understanding that autonomy minimizes disruption (e.g., Schweizer, 2005). Namely, our study identifies post-merger behaviors that are not disruptive. Past research has highlighted the detrimental and differential effects of disruptive integration in the context of employee departure and reduced productivity (Cannella and Hambrick, 1993; Lubatkin et al., 1999; Paruchuri et al., 2006; Walsh, 1989). Our research complements this work by finding that brokers recombined more knowledge from the other firm and that centrality was related in an inverted U-shaped relation with the extent of recombining the other firm’s knowledge following a merger. Consequently, our paper extends prior research on the differential effects on personnel by showing that behaviors other than departure and productivity are also differentially affected by mergers and integration processes. Because the identification of these behavioral changes can help mitigate disruptions and create synergies in the context of integration, this paper also contributes to unraveling the integration dilemma (e.g., Angwin and Meadows, 2015; Graebner et al., 2017; Haxespilagh and Jemison, 1991; Ranft and Lord, 2002; Zaheer et al., 13).

Third, we link the network positions of inventors to their recombination choices in a dynamic context. Much of the recent research examines a firms’ internal network dynamics to understand information flows, status, and innovation productivity (Brass and Burkhardt, 1993; Ibarra, 1993; Tushman, 1977; Tushman and Romanelli, 1983). Almost all these studies explore stable firm contexts. Our context contrarily employs the concepts of centrality and brokerage in the intra-firm inventor network to understand changes in knowledge recombination patterns in a changing, unstable post-merger context. In this way, we address Graebner et al.’s (2017) call to understand the reconfiguration of networks following MA.

Finally, our results suggest several managerial implications. In the context of our focus on highly central inventors’ recombination choices, our findings show that these inventors recombined less knowledge from the other firm. This result, along with Paruchuri et al.’s (2006) finding that central inventors are the ones whose productivity is most reduced following an acquisition, show that the most central inventors stand to lose in more than one way following an MA. These findings pose an interesting issue in mergers where firms are acquired or merged to gain star inventors (Wysocki, 1997). These star inventors, who usually tend to be central, would probably not only be less productive but also would not be the ones exploiting the potential for leveraging the other firm’s knowledge base following an MA.

Additionally, in the context of our focus on brokers, it is interesting to note that some past work linked ability not only to inventors’ abilities to access and utilize knowledge but also to the concept of absorptive capacity (e.g., Aalbers et al., 2013; Qi Dong et al., 2017; Junnii and Sarala, 2013; Tsui, 2001). According to these authors, inventors in various network positions such as brokers, can access and utilize diverse knowledge but this access is expected to be limited by their absorptive capacity, often leading researchers to theorize an inverted-U relationship between brokerage and the ability to recombine knowledge. Our theorizing and results suggest a linear relationship. We understand our result as suggesting that the innate curiosity and interest in new knowledge that characterizes brokerage and which position brokers as likely to thrive in post-merger settings. Following a merger, brokers have the opportunity to access the knowledge of the other firm and to contribute to the new firms’ knowledge trajectory.

Limitations, future avenues, and conclusions

In closing, this paper has some limitations, which could form avenues for future research. While the in-depth exploration of one merger is useful, it raises the issue of external validity. This study forms a good starting point for understanding the relationship between mergers and inventors’ knowledge recombination patterns in the context of the GA concept, but future studies could expand our findings by studying different mergers and different types of integration contexts. Here, we highlighted the context of an R&D motivated merger in which labs maintained their autonomy to allow us to reduce the likelihood that integration disruptions, such as a culture clash or a threat to identity, impact the work of inventors. These disruptions were also minimized in our context because the firms in our setting were of relatively equal size. Future studies should examine whether the processes differ in other types of settings. For example, size differences could bring out the feelings of conquest and conquered which may affect the dynamics found here. Thus, future work could explore how dynamics unfold when the merger or acquisition consists of unequal sized firms.

Relatedly, our context is unique in that firms pursued a strategy of maintaining autonomy although they wanted to achieve long-term synergies in the research trajectories of merging firms. The Haxespilagh and Jemison (1991) framework could be interpreted as

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recommending integration as a path to synergies. This potential contrast suggests that, broadly speaking, mergers are quite different in their characteristics and not entirely common. For these reasons, research is likely best served by continuing to do work on both large scale data sets that aggregate data on several mergers alongside more detailed case studies that appreciate the uniqueness of each case. Pursuing such a rich research agenda would allow us to expose a broader set of explanatory mechanisms and to gain, as a field, a stronger understanding of the flow of knowledge.

An interesting idea in this context is the concept of common ground as a potential explanatory mechanism (e.g., Puranam, et al., 2009). The presence of common ground among inventors of merging firms suggests that not only do inventors know the same things, but that they also realize that they know them. Therefore, the presence of common ground among inventors of both firms would reduce the effort required to integrate the knowledge of the merged firm as commonly ground knowledge is easier to discuss, evaluate, and integrate. Such a mechanism could potentially serve to qualify which of the forms of integration is warranted in which settings and to extend the foundational Hangeslagh and Jemison (1991) framework. In this context, an interesting avenue for future research would be to generate a large research sample in which the presence of common ground varies in the context of different mergers.

Another limitation arises from the use of patent data. Specifically, we rely on the patent data to explore issues of knowledge recombination. Because the pharmaceutical industry relies heavily on patents to protect their intellectual property, the selection of a merger in the pharmaceutical industry decreases the problems associated with patent data. Nevertheless, patent data do not capture sticky and tacit knowledge and also do not capture knowledge leverage in departments other than R&D departments. Future studies could expand research by using other kinds of data to explore knowledge leverage in other departments or industry settings.

Despite these limitations, this study makes significant theoretical and empirical contributions to knowledge recombination research by exploring changes in knowledge recombination dynamics following a merger. By considering inventors’ differential recombination choices, this paper adds to our understanding of how mergers can affect not only the primary research of a firm but also its generative research trajectory. In so doing, the paper addresses the call to examine the effects of MA over a longer time horizon (Graebner et al., 2017). Practically, our paper suggests that managers should identify and nurture certain types of inventors following a merger to be able to better leverage the knowledge bases of merging firms.

Appendix table

| Selection Model Estimating the Probability of Inventor Patenting Post-integration |
|----------------------------------|----------------------------------|
| Fixed-effects Probit Model       |                                  |
| Intercept                        | −1.32*** (.266)                 |
| Centrality                       | 0.602* (.262)                   |
| Span of Structural Hole          | 0.587* (.252)                   |
| Tenure                           | −0.042** (.014)                 |
| Pre-integration Productivity     | 0.065* (.027)                   |
| Pre-integration Collaboration    | −0.190 (.158)                   |
| Breadth of Expertise             | 0.156 (.091)                    |
| Potential Collaborators          | 0.001* (.0004)                  |
| N                                | 539                             |
| Wald Chi-square                  | 78.07                           |

Notes: ***: p < .001; **: p < .01; *: p < .05; two-tailed test.

References


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