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Inter-Firm Inventor Collaboration and Path-Breaking Innovation: Evidence From Inventor Teams Post-Merger

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Abstract

Using a large and novel data set over the period of 1976 to 2019 tracking inventors' career paths following mergers and acquisitions, we show that collaboration between acquirer and target inventors post-merger is associated with more path-breaking patents than those filed by either acquirer or target inventor-only teams. We further show that such collaboration is more important in improving acquirers' innovation capabilities than hiring target inventors and knowledge spillovers. Finally, we show that recombining tacit knowledge embodied in the human capital of acquirer and target inventors is likely the mechanism. We conclude that inter-firm inventor collaboration is one key means for achieving synergies.

I. Introduction

In this article, using novel and comprehensive inventor- and patent-level data, we fill a void in the literature by studying one important benefit of mergers and

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acquisitions (M&As): fostering inter-firm inventor collaboration that would not have been possible without broadening the boundaries of a firm. We address the following two questions: i) how do inter-firm inventor teams help expand acquirers' innovation capabilities? and ii) what inventor characteristics are associated with inter-firm collaboration post-merger?

The benefits of M&As in the realm of corporate innovation and firm value, such as creating synergies from owning complementary assets (Grossman and Hart (1986), Hart and Moore (1990), Rhodes-Kropf and Robinson (2008), and Bena and Li (2014)), gaining access to technology (Sevilir and Tian (2012), Phillips and Zhdanov (2013)), and eliminating competition (Cunningham, Ederer, and Ma (2021)), are well documented in the literature. A natural question to ask is if these benefits are real, then why do we not see more deals in the real world? The answer is that various cost considerations argue against deal making: the loss of autonomy (Phene, Tallman, and Almeida (2012), Seru (2014)), the risks of cultural misalignment and changes in incentives (Fulghieri and Sevilir (2011), Li, Mai, Shen, and Yan (2021)), and cheaper ways for firms to collaborate (Enkel, Gassmann, and Chesbrough (2009), Chemmanur, Loutskina, and Tian (2014), and Li, Qiu, and Wang (2019)). Offsetting these costs, Enkel, Gassmann, and Chesbrough (2009) highlight losses of control and core competence as key risks when firms engage in inter-firm R&D and innovation. Not surprisingly, firms with state-of-the-art technology are often reluctant to collaborate because the tacit nature of their core technology is an important source of competitive advantage and firm value (Winter (1987), Kogut and Zander (1996)). Relatedly, knowledge diffuses more easily within a firm than between firms via close interpersonal ties and networking (Kogut and Zander (1992)). Expanding firm boundaries via M&As thus emerges as a viable mechanism for facilitating inter-firm collaboration and knowledge transfer.

The property rights theory of the firm developed by Grossman and Hart (1986) and Hart and Moore (1990) and its extension to M&As by Rhodes-Kropf and Robinson (2008), posit that in a world with incomplete contracting, complementary assets should be placed under the control of a single firm to achieve synergies. In the sphere of technology-driven acquisitions in which human capital is a key asset, we expect that common ownership will expand the opportunity set for collaboration between acquirer and target inventors who possess complementary technologies (Holmström and Roberts (1998), Hart and Holmström (2010), and Fulghieri and Sevilir (2019)), and that inter-firm inventor collaboration results in more path-breaking innovation than intra-firm inventor collaboration post-merger.

To examine how acquirers realize human capital synergies after deal completion, we compile a large and novel U.S. inventor- and patent-level data set over the period of 1976 to 2019. Our inventor-level data allow us to track acquirer and target inventors' career paths, which is key to determining whether post-merger inter-firm inventor collaboration has occurred. Our patent-level data allow us to examine the relation between acquirer and target inventors' collaborative efforts and their innovation outcomes. Our focus on comparing inter-firm inventor teams vis-à-vis intra-firm inventor teams post-merger offers new insights into the firm-level treatment effect of M&As on corporate innovation activities as established in Bena and Li (2014): the recombination of human capital in acquirer and target firms post-merger is the channel.

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To capture an inventor's or an inventor team's patenting performance, we introduce three new measures of path-breaking innovation to the M&A literature: radical patents based on the (ex ante) unprecedented combination of knowledge (e.g., Weitzman (1998), Eggers and Kaul (2018), and Bernstein, Diamond, McQuade, and Pousada (2019)); impactful patents based on the (ex post) number of citations (e.g., Balsmeier, Fleming, and Manso (2017), Eggers and Kaul (2018)); and valuable patents based on the (ex post) movement in stock prices in the days immediately after a patent has been issued to a firm (Kogan, Papanikolaou, Seru, and Stoffman (2017)).

Using a sample of 28,166 acquirer inventors and 4,257 target inventors in 942 deals announced and completed between 1981 and 2012 with inventor career information spanning 1976–2019, we first show that post-merger, compared to patents by acquirer/target inventor-only teams, patents produced by collaboration between acquirer and target inventors are more likely to be radical, impactful, and valuable. In terms of economic significance, the number of radical/impactful/valuable patents by inventors on hybrid teams is 0.250/0.204/0.222 more than that by inventors not on hybrid teams. These differences are economically significant given the number of radical/impactful/valuable patents by acquirer/target inventor-only teams at 0.144/0.139/0.169 over the 5-year period post-merger. As far as we are aware, we provide one of the first pieces of evidence on how M&As enable acquirers to expand their innovation capabilities: collaboration between acquirer and target inventors post-merger is associated with more path-breaking innovation than acquirer/target inventor-only teams.

We then examine what target inventor characteristics are associated with more collaboration with acquirer inventors post-merger. We find that acquirer inventors are more likely to collaborate with target inventors who share the same core expertise and are geographically proximate; whose significant collaborators are not staying in the merged firm; and who as inventors are less specialized, are highly productive (i.e., enjoy star recognition), and have large networks. To the extent that those in the latter two categories are more capable, our findings suggest that M&As allow acquirers to tap into opportunities for collaboration with target inventors who would otherwise be inaccessible or unavailable. We further show that acquirer inventors produce more path-breaking innovation via collaboration with target inventors than target inventors do via collaboration with acquirer inventors, highlighting the importance of inter-firm inventor collaboration to acquirers.

In addition to providing the opportunities to collaborate with target inventors, M&As offer 2 other well-known benefits that help improve acquirers' innovation performance: access to target inventors' patenting output and knowledge spillovers from target firms (Holmström and Roberts (1998), Ahuja and Katila (2001)). We show that collaboration between acquirer and target inventors is more important in expanding acquirers' innovation capabilities than just having target inventors working for acquirers and/or receiving knowledge spillovers. We further show that the positive association between collaboration and path-breaking innovation is unlikely due to (codified) knowledge spillovers (e.g., through reading patent filings) between the acquirer and its target firm. Instead, our results suggest that tacit knowledge transfer (e.g., through social interactions, learning, and mentoring) is the mechanism underlying the positive association between inter-firm inventor collaboration and path-breaking innovation.

We next employ deal-level data to illustrate the counterfactual (i.e., what would have been the innovation output of inventors of the acquirer-target pairs either on a hybrid term or not, had there been no merger). We first show a steep increase in the frequency of collaboration between acquirer and target inventors post-merger, suggesting that there had been a binding constraint for collaboration and knowledge transfer inside the acquirer pre-merger. To illustrate the counterfactual, we employ a control sample of matched pairs that have similar characteristics and a similar estimated likelihood of merging, but that do not merge. Compared to the number of hybrid teams formed in acquirer control-target (acquirer-target control) pairs post-merger, which is trivial, the number of hybrid teams formed in acquirer-target pairs post-merger on average is 0.815 (1.713) more per pair-year. Compared to the increase in the number of radical/impactful/valuable patents (radical/impactful patents) by hybrid teams in acquirer control-target (acquirer-target control) pairs from pre- to post-merger, the increase by hybrid teams in acquirer-target pairs is on average 0.852/0.766/0.378 (0.713/0.494) more per pair-year.

In summary, our patent- and inventor-level analyses provide cross-sectional evidence on the positive association between inter-firm inventor teams and path-breaking innovation post-merger, and our deal-level analyses further establish the counterfactual. Taken together, our findings shed light on a specific means (i.e., inter-firm inventor collaboration) through which M&As foster corporate innovation (Bena and Li (2014)).

Our article differs from prior work, and thus contributes to the M&A and innovation literature, in three ways. First, using novel inventor- and patent-level data, our article provides new large-sample evidence on M&As as an effective way for bringing acquirer and target inventors of diverse knowledge and innovation experience together under the same roof and facilitating the recombination of knowledge, resulting in path-breaking innovation. Second, our article highlights a number of inventor characteristics, such as inventor productivity and network size, that are conducive to achieving human capital synergies in M&As. Third, our article provides suggestive evidence that the positive association between acquirer and target inventor collaboration and path-breaking innovation post-merger is more likely due to tacit knowledge transfer rather than codified knowledge spillovers. More broadly, our article suggests that inter-firm inventor collaboration helps address the pressing issue of the scarcity of original ideas (Bloom, Jones, Van Reenen, and Webb (2020)).

Our article is closely related to the literature on post-merger restructuring and the boundaries of the firm (Maksimovic and Phillips (2001), Schoar (2002), and Maksimovic, Phillips, and Prabhala (2011)). While also focusing on cross-sectional variations in post-merger outcomes as those studies, our article is the first in the literature to study reorganization of inventor teams post-merger.

Our article is also related to an emerging strand of the M&A literature examining human capital synergies (or the lack thereof) in acquisitions (Tate and Yang (2016), Lee, Mauer, and Xu (2018), Ma, Ouimet, and Simintzi (2018), and Lagaras (2020)). Seru (2014) presents evidence of a significant drop in target inventors'

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productivity (as measured by the number of citations per patent) in diversifying mergers. Different from and complementary to Seru (2014), our article shows a steep increase in the frequency of inter-firm inventor collaboration post-merger that results in more path-breaking innovation compared to intra-firm inventor teams.

Finally, our article is also related to the economics literature on knowledge spillovers and growth (Jaffe (1986), Jaffe, Trajtenberg, and Henderson (1993), and Ahuja and Katila (2001)). This literature further recognizes that state-of-the-art technologies are often tacit knowledge embodied in the human capital of a firm's employees that cannot easily be transferred across firms (Winter (1987), Cohen and Levinthal (1990), Leonard-Barton (1995), and Song, Almeida, and Wu (2003)). Complementary to those studies, our article identifies one specific way through which tacit knowledge transfer occurs (i.e., via inter-firm inventor teams formed after deal completion).

II. The Conceptual Framework

A. M&As and Collaboration

Fulghieri and Sevilir (2011) highlight a negative effect of mergers on employee incentives to innovate, because mergers reduce competition for human capital, allowing combined firms to extract greater rents from employees. The net effect is that mergers can be harmful for corporate innovation and new product development. Seru (2014) finds that diversifying mergers stifle innovation at target firms, which experience high inventor turnover and low patenting productivity post-merger. Cunningham et al. (2021) posit that large pharmaceutical firms acquire innovative bio-tech firms solely to discontinue the latter's R&D projects and preempt future competition and estimate that 5%–7% of acquisitions in their sample are killer acquisitions.

On the other hand, the property rights theory of the firm developed by Grossman and Hart (1986) and Hart and Moore (1990) and its extension to M&As by Rhodes-Kropf and Robinson (2008), conclude that in a world with incomplete contracting, complementary assets should be placed under the control of a single firm to achieve synergies.

Fulghieri and Sevilir (2019) develop a model of human capital integration after deal completion. In their model, employees in the combined firm choose between collaboration to create synergies, and competition to extract greater resources from corporate headquarters. The authors show that incentives to collaborate are stronger in mergers between firms with greater human capital complementarity because when employees collaborate, they learn from each other and enhance their own human capital/productivity; and the effect is larger when there is more to learn from employees of the other firm. Their model provides the conceptual framework for our empirical analysis in this article.

In summary, although M&As may be detrimental for individual employees post-merger (e.g., due to redundancy), there is a bright side: M&As bring employees of acquirers and target firms together, and give them the opportunity to exchange knowledge and collaborate. To the extent that M&As are used to place complementary assets, including the human capital attached to those assets, under

1 roof, we expect that common ownership will result in more knowledge transfers and collaboration between acquirer and target inventors who possess complementary technologies (Holmström and Roberts (1998), Hart and Holmström (2010), and Fulghieri and Sevilir (2019)).

B. Collaboration and Path-Breaking Innovation

Radical innovation, by definition, is a combination of knowledge from domains that might ordinarily not be connected (e.g., Weitzman (1998), Eggers and Kaul (2018), and Bernstein et al. (2019)). Taylor and Greve (2006), Singh and Fleming (2010), and Fitzgerald and Liu (2021) show that teams with diverse knowledge domains are more likely to generate cutting-edge ideas and novel combinations of knowledge components. Bernstein et al. (2019) find that combining the different knowledge bases of immigrant and native inventors is especially important in producing highly valuable patents.

Post-merger, acquirer inventors can collaborate with target inventors; with each bringing a different set of knowledge domains and past experience to their collaboration, the potential for path-breaking innovation is heightened. Moreover, target inventors may be uniquely positioned to facilitate acquirer inventors in exploring novel combinations of a target firm's core technology embodied in their human capital (i.e., tacit knowledge) in addition to codified knowledge (e.g., patent filings). We thus expect that M&As will facilitate radical innovation through collaboration between acquirer and target inventors.[1]

III. Sample Formation and Variable Constructions

A. The M&A Sample, the Patent Sample, and the Inventor Sample

Our M&A sample comes from Thomson Financial's SDC Platinum Database on Mergers and Acquisitions. We start with all U.S. deals announced and completed between Jan. 1, 1981 and Dec. 31, 2012. We impose the following filters to obtain our final sample: i) the deal is classified as "Acquisition of Assets (AA)," "Merger (M)," "Acquisition (A)," or "Acquisition of Majority Interest (AM)" by the data provider; ii) both the acquirer and its target firm are U.S. public firms; iii) the acquirer holds less than 50% of the shares of the target firm before bid announcement and ends up owning 100% of the shares of the target firm through the deal; iv) the deal value is at least $1 million (in constant 2019 dollars); v) the relative size of the deal (i.e., the ratio of transaction value over an acquirer's book value of assets) is at least 1%; and vi) both the acquirer and its target firm have at least 1 inventor in the year prior to bid announcement. We end up with a sample of 942 completed deals.

[1]It is worth noting that M&As are not the only way to expand firms' innovation capabilities; innovative firms also turn to hiring talent and forming strategic alliances and corporate venture capital to facilitate inter-firm knowledge transfer (Mowery, Oxley, and Silverman (1996), Song et al. (2003), Chemmanur et al. (2014), and Li et al. (2019)). In contrast, M&As ensure that target inventors' human capital is not separated from the systems, processes, and routines with which it can be effectively utilized (Hart and Holmström (2010)) and facilitate tacit knowledge transfer via social interactions, learning, and mentoring between acquirer and target inventors (Winter (1987), Kogut and Zander (1996), and Song et al. (2003)).

Our sample period starts in 1981, when data coverage on M&As started. Our M&A sample ends in 2012 for the following reason. The year 2019 was the last year in which the Kogan et al.'s Patent and Citation File (2017, KPSS database) has coverage; given the well-known patent approval lag between application and award, the year 2017 would be the last year in which patent-related measures do not suffer serious truncation bias. Since we require a 5-year window after the year of deal completion to examine post-merger innovation outcomes, the last year for completed deals to have a full post-merger 5-year window is 2012.

In our analysis, an inventor's place of employment is identified by the assignee of her patent. For example, an inventor who applies for 1 patent with firm A in 2000 and another with firm B in 2005 is assumed to be an employee of firm A in 2000 and an employee of firm B in 2005. We then assume that her job change occurs at the midpoint between the 2 patent application years following convention (e.g., Marx, Strumsky, and Fleming (2009), Hombert and Matray (2017)).[2] Inventors are included in the sample for their entire active career (i.e., the period between the year of their first and the year of their last patent applications). A detailed description of our matching scheme to link inventors in the PatentsView database with U.S. public firms in the CRSP database is provided in Appendix IA1 in the Supplementary Material. An acquirer (a target) inventor is identified as someone whose active career spans the year before bid announcement (i.e., year $ayr - 1$) and whose employer at that particular point in time is the acquirer (target firm). Our final sample of inventors consists of 28,166 acquirer inventors and 4,257 target inventors who have applied for at least 1 patent in the target classes (to be defined below) over the period from 1 year after deal completion (i.e., year $cyr + 1$) to 5 years after (i.e., year $cyr + 5$).

An acquirer often has multiple segments of business that might or might not overlap with the segment(s) of its target (e.g., Microsoft's acquisitions of Skype and GitHub). To examine the contribution of target inventors to the innovation performance of the acquirer relative to that of incumbent acquirer inventors in an apples-to-apples comparison, we focus on technology classes in which target inventors produce patenting output in the merged firms. Consider Microsoft's 2011 acquisition of Skype as an example; while Skype specializes in telecommunications applications, Microsoft has divisions in many different areas, such as operating systems (Windows), a suite of office applications (Office), cloud computing (Azure), and gaming (Xbox), and at the time of the acquisition had a telecommunications application (MSN messenger). To examine Skype inventors' contributions to Microsoft's innovation performance, we focus on technology classes in which Skype inventors produce patents after the acquisition, which are more likely to be in telecommunications applications than in other areas such as operating systems. For this reason, for each year over the period $cyr + 1$ to $cyr + 5$, we define target classes as the technology classes in which target inventors (either alone or on a hybrid team with acquirer inventors) apply for at least 1 patent in that year. The term target classes thus refer to the specific technological areas in which target inventors file patents at a merged firm following deal completion. Among patents in the target classes, we identify those that involve at least 1 target (acquirer) inventor

[2]The mean/median number of years between 2 adjacent patents by sample inventors is 0.8 (0) year.

who works in the target firm (acquirer) in $ayr - 1$. Our final sample of patents consists of 51,286 patents applied for over the period $cyr + 1$ to $cyr + 5$ and in the target classes in their application year.

B. Measures of Path-Breaking Innovation

To capture path-breaking innovation, we introduce three new measures to the M&A literature (see detailed definitions in the Appendix): radical patents based on (ex ante) unprecedented knowledge combination (e.g., Weitzman (1998), Eggers and Kaul (2018), and Bernstein et al. (2019)), impactful patents based on the (ex post) number of citations (Phene et al. (2012), Balsmeier, Fleming, and Manso (2017), and Eggers and Kaul (2018)), and valuable patents based on the (ex post) price reaction to the news that a patent has been issued to a firm (Kogan et al. (2017)). Specifically, a patent is radical if it draws on knowledge that has never or rarely been used before by inventors in the same field. The measure looks at the class-to-class citation pattern of patents to determine how rare a given citation is. If patents in Class A frequently cited patents in Class B, then a new A-to-B citation would be common and expected (i.e., neither rare nor radical). If however, hardly any patent in Class A cited a Class B patent in the last 5 years, then such a citation would signal an attempt at a more radical recombination. At the patent level, the measure looks at all citations a patent makes and takes the value of the most unlikely citation. We define radical patents as those in the top 5th percentile in terms of drawing on fundamentally new knowledge among granted patents in the same technology class-year (Eggers and Kaul (2018)). A patent is impactful if the number of citations it received (up to 2019) is in the top 5th percentile among granted patents in the same technology class-year. A patent is valuable if its change in market capitalization over the 3-day period from the patent issuance day to 2 days thereafter (Kogan et al. (2017)) is in the top 5th percentile among granted patents in the same technology class-year.

C. Sample Overview

Table 1 presents the summary statistics of sample deals and firms. Our M&A sample consists of 942 deals announced and completed over the period of 1981 to 2012. We show that over 40% of these deals take place between firm pairs in different 2-digit SIC industries. The average/median ratio of transaction value to acquirer book value of assets is 46%/23%. About a third of the deals are paid entirely in cash, and about another third are paid entirely by stock. Overall, deals in our sample are not very different from deals in much larger samples such as Li, Qiu, and Shen (2018).

In terms of acquirer and target firms in our sample, acquirers are far larger than their target firms. Acquirers also have higher TOBIN'S_Q, ROA (return on assets), and PRIOR_YEAR_STOCK_RETURN than their target firms.

D. Inventor Characteristics and Patenting Outcome

Panel A of Table 2 presents the summary statistics of inventor characteristics as of $ayr - 1$ for those inventors who apply for patents in the target classes over

TABLE 1
Summary Statistics of Sample Deals and Firms

Table 1 presents the summary statistics of M&A deal characteristics and acquirer and target firm characteristics. Our sample consists of 942 deals announced and completed over the period 1981–2012 that satisfy the following conditions: i) the deal is classified as "Acquisition of Assets," "Merger," "Acquisition," or "Acquisition of Majority Interest" by the data provider; ii) both the acquirer and its target firm are U.S. public firms; iii) the acquirer holds less than 50% of the shares of the target firm before bid announcement and ends up owning 100% of the shares of the target firm through the deal; iv) the deal value is at least $1 million (in 2019 dollars); v) the relative size of the deal (i.e., the ratio of transaction value over an acquirer's book value of assets) is at least 1%; and vi) both the acquirer and its target firm have at least 1 inventor in the year before bid announcement (*ayr*-1). All ratios are winsorized at the 1st and 99th percentiles. Detailed variable definitions are provided in the Appendix.

	Mean	Std. Dev.	Min	25th Percentile	Median	75th Percentile	Max
Deal characteristics							
DIVERSIFYING	0.433	0.496	0.000	0.000	0.000	1.000	1.000
RELATIVE_SIZE	0.460	1.004	0.010	0.085	0.232	0.494	15.643
ALL_CASH	0.329	0.470	0.000	0.000	0.000	1.000	1.000
ALL_STOCK	0.340	0.474	0.000	0.000	0.000	1.000	1.000
Acquirer characteristics							
SALES	10,130	21,182	0.000	475	2,318	9,579	193,517
BOOK_ASSETS	15,777	78,970	1.224	558	2,602	10,398	2,116,445
TOBIN'S_Q	2.597	3.310	0.354	1.323	1.868	2.844	83.692
ROA	0.118	0.204	−2.282	0.088	0.146	0.206	0.506
LEVERAGE	0.188	0.162	0.000	0.056	0.167	0.273	0.967
PRIOR_YEAR_STOCK_RETURN	0.287	0.743	−0.992	−0.063	0.179	0.455	8.301
Target characteristics							
SALES	2,480	8,038	−0.162	81	266	1,234	93,237
BOOK_ASSETS	4,750	45,699	1.864	95	302	1,228	1,258,274
TOBIN'S_Q	2.244	2.166	0.498	1.175	1.614	2.428	29.103
ROA	0.033	0.305	−3.285	0.012	0.107	0.167	0.493
LEVERAGE	0.182	0.202	0.000	0.014	0.131	0.285	1.749
PRIOR_YEAR_STOCK_RETURN	0.195	1.040	−0.982	−0.264	0.018	0.385	15.688
No. of obs.	942						

TABLE 2
Summary Statistics of Inventors and Patents After Deal Completion

Table 2 presents the summary statistics of inventor and patent characteristics after deal completion. The post-merger inventor sample consists of 28,166 acquirer inventors and 4,257 target inventors who have applied for at least 1 patent in the target classes over the period from 1 year after deal completion ($cyr+1$) to 5 years after ($cyr+5$). Acquirer (target) inventors are inventors working at the acquirer (target firm) in $ayr-1$. Target classes in year t are patent classes in which target inventors have applied for at least 1 patent. Panel A presents the summary statistics of inventor characteristics. Panel B presents the summary statistics of 51,286 patents in the target classes applied for over the period $cyr+1$ to $cyr+5$ by acquirer and target inventors and whose assignee is the merged firm (or the target firm in cases where it remains standalone after deal completion). Detailed variable definitions are provided in the Appendix. *p*-values for testing the difference in means and medians are presented at the end of the table.

Panel A. Characteristics of Inventors in ayr − 1

	Acquirer Inventors			Target Inventors			*p*-Value	
	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median	*t*-Test	Wilcoxon
INVENTOR_SIGNIFICANT_CO-INVENTOR_STAY	0.584	0.493	1.000	0.569	0.495	1.000	0.064	0.063
STAR_INVENTOR	0.140	0.347	0.000	0.124	0.329	0.000	0.004	0.005
INVENTOR_NETWORK (RAW)	104.772	199.806	43.000	78.529	143.515	26.000	0.000	0.000
INVENTOR_SPECIALIZATION	0.535	0.174	0.599	0.504	0.183	0.486	0.000	0.000
#PATENTS	8.418	15.781	4.000	7.807	12.578	4.000	0.004	0.639
#CITATION-WEIGHTED_PATENTS	73.532	137.533	30.000	68.000	140.670	25.000	0.005	0.000
No. of obs.	28,166			4,257				

Panel B. Characteristics of Patents by Different Inventor Teams After Deal Completion

	By Hybrid Teams			By Acquirer/Target Inventor-Only Teams			*p*-Value	
	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median	*t*-Test	Wilcoxon
RADICAL	0.087	0.281	0.000	0.050	0.219	0.000	0.000	0.087
IMPACTFUL	0.062	0.241	0.000	0.049	0.215	0.000	0.005	0.002
VALUABLE	0.080	0.271	0.000	0.062	0.241	0.000	0.001	0.000
No. of obs.	2,739			48,547				

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the period $cyr + 1$ to $cyr + 5$ (detailed variable definitions are provided in the Appendix). For each year, target classes are technology classes in which at least 1 patent applied for in that year involves target inventors.

We show that acquirer inventors experience similar degrees of disruption to their teams as target inventors: 58% of acquirer inventors experience disruption to their collaborative teams, compared to 57% of target inventors (albeit the difference is statistically significant at the 10% level). We further show that acquirer inventors are significantly more likely to be star inventors than target inventors: 14% for the former versus 12% for the latter. The average size of a coinventor network is 105 for acquirer inventors and 79 for target inventors. We further show that acquirer inventors are significantly more specialized than target inventors. Finally, we show that both groups of inventors have similar patenting outcomes as measured by the median number of patents, and acquirer inventors' patents generate significantly more citations than those of target inventors.

Jones (2009) and Jaravel, Petkova, and Bell (2018) show that the practice of forming inventor teams is growing over time, and that the majority of patents in the U.S. are produced by teams of 2 or 3 inventors. The mean (median) inventor team size in our inventor sample is 3.2 (3). The mean/median share of acquirer/target inventors on hybrid teams is 0.40/0.33 (0.35/0.33), as a hybrid team could also include other inventor(s) who are not identified as acquirer/target inventor(s) as of $ayr - 1$. The share of a single inventor accounts for about a fifth of our sample.

Panel B of Table 2 presents the summary statistics of patents in the target classes produced by collaboration between acquirer and target inventors (i.e., hybrid teams) and by acquirer/target inventor-only teams over the period $cyr + 1$ to $cyr + 5$. We show that patents produced by inter-firm inventor teams are significantly more likely to be radical than those produced by intra-firm inventor teams: close to 9% of patents by the former compared to only 5% by the latter. Moreover, more than 6% of patents by hybrid teams are impactful, compared to only 5% of patents by acquirer/target inventor-only teams. Finally, we show that 8% of patents by hybrid teams are valuable, compared to about 6% of the patents by acquirer/target inventor-only teams.

In untabulated analysis, we find that the Pearson correlations between radical and impactful, between radical and valuable, and between impactful and valuable patents are 0.025, 0.012, and 0.026, respectively, suggesting that our three measures capture distinct facets of path-breaking innovation.

Next, we employ multivariate analysis to examine whether and how acquirers achieve human capital synergies.

IV. Main Findings

In this section, we provide patent- and inventor-level evidence that collaboration between acquirer and target inventors post-merger is associated with path-breaking innovation, and further identify inventor characteristics that are conducive to collaboration.

A. Collaboration Between Acquirer and Target Inventors and Path-Breaking Innovation

Table 3 reports our investigation of how path-breaking innovation occurs post-merger by making use of inventor team information at the patent level. Panel A of Table 3 presents the patent-level linear probability regression results on the relation between collaboration and path-breaking innovation controlling for deal fixed effects. The indicator variable, HYBRID_TEAM, takes the value of 1 if inventors of a patent include at least 1 target inventor and at least 1 acquirer inventor, and 0 otherwise. The dependent variables are the indicator variables for radical/impactful/valuable patents. The baseline case is patenting output by acquirer/target inventor-only teams.

We show that compared to patents by acquirer/target inventor-only teams, patents by hybrid teams are more likely to be radical: the likelihood is higher by 2.3 percentage points. This difference is economically significant given that the share of patents by acquirer/target inventor-only teams that are radical is 5.0 percentage points, suggesting an almost 50% increase in the likelihood of a patent being radical. Moreover, we show that patents by large inventor teams are more likely to be radical and impactful but less likely to be valuable.[3]

Panel B of Table 3 examines the relation between an inventor on hybrid teams and her number of path-breaking patents using inventor-level data. The indicator variable, ON_HYBRID_TEAM, takes the value of 1 if an inventor is on at least 1 hybrid team over the period $cyr + 1$ to $cyr + 5$, and 0 otherwise. The dependent variables are an inventor's number of radical/impactful/valuable patents. The baseline case is the number of radical/impactful/valuable patents filed by inventors, not on any hybrid teams over the period $cyr + 1$ to $cyr + 5$.

Consistent with the patent-level results in Panel A of Table 3, we show that compared to inventors not on hybrid teams, inventors on hybrid teams produce more radical/impactful/valuable patents post-merger. In terms of economic significance, the number of radical/impactful/valuable patents by inventors on hybrid teams is 0.250/0.204/0.222 more than the corresponding numbers by inventors not on hybrid teams. These differences are economically significant given the number of radical/impactful/valuable patents by acquirer/target inventor-only teams at 0.144/0.139/0.169 over the 5-year period post-merger. Our finding thus provides novel evidence on the unique benefit of M&As in expanding acquirers' innovation capabilities: collaboration between acquirer and target inventors post-merger is associated with more path-breaking innovation than acquirer/target inventor-only teams.

There are 2 possible reasons why inter-firm inventor collaboration is associated with more path-breaking information. One is the direct effect of collaboration

[3]In untabulated analysis, we find that hybrid teams are more ethnically diverse than teams formed by acquirer or target inventors only. Our team-level ethnic diversity measure is defined as one minus *Ethnicity HHI* of Griffin, Li, and Xu (2021). We further find that our main findings in Panel A of Table 3 remain after controlling for the ethnic diversity of inventor teams, suggesting that the positive association between hybrid teams and path-breaking innovation is unlikely driven by the ethnic diversity of inventor teams. Thus, it is likely that the recombination of different innovation experiences embedded in inventor human capital matters. We thank an anonymous referee for suggesting this analysis.

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TABLE 3

Collaboration Between Acquirer and Target Inventors and Path-Breaking Innovation

Table 3 examines the relation between hybrid teams and path-breaking innovation over the period $cyr+1$ to $cyr+5$. Panel A presents the linear probability regression results where the dependent variables are the indicator variables for radical, impactful, and valuable patents. The sample consists of 51,286 patents in the target classes applied for by 28,166 acquirer inventors and 4,257 target inventors over the period $cyr+1$ to $cyr+5$. The baseline case is the patenting output by acquirer/target inventor-only teams. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. Panel B presents the OLS regression results where the dependent variables are the number of radical/impactful/valuable patents. The sample consists of 28,166 acquirer inventors and 4,257 target inventors who file at least 1 patent in the target classes over the period $cyr+1$ to $cyr+5$. The baseline case is the patenting output by inventors not on hybrid teams. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. Detailed variable definitions are provided in the Appendix. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Panel A. Collaboration Between Acquirer and Target Inventors and Path-Breaking Innovation (patent level)

	RADICAL	IMPACTFUL	VALUABLE
	1	2	3
HYBRID_TEAM	0.023**	0.010	0.006
	(0.009)	(0.007)	(0.008)
#INVENTORS	0.009**	0.021***	−0.010**
	(0.004)	(0.004)	(0.004)
No. of obs.	51,286	51,286	51,286
Adj. R^2	0.036	0.062	0.155

Panel B. Collaboration Between Acquirer and Target Inventors and Path-Breaking Innovation (inventor level)

	#RADICAL_PATENTS	#IMPACTFUL_PATENTS	#VALUABLE_PATENTS
	1	2	3
ON_HYBRID_TEAM	0.250***	0.204***	0.222***
	(0.065)	(0.043)	(0.058)
No. of obs.	32,423	32,423	32,423
Adj. R^2	0.055	0.057	0.211

from recombination of knowledge and expertise (e.g., Taylor and Greve (2006), Fitzgerald and Liu (2021)), and the other is the indirect effect of collaboration that calls for more capable inventors to join hybrid teams, so it is individual inventors' capabilities, and not collaboration per se, that drive the result. Our subsequent analysis suggests that both effects are at play.[4]

Overall, Table 3 provides novel patent- and inventor-level evidence on how M&As achieve human capital synergies: By expanding firm boundaries, M&As enlarge the opportunity set for acquirer inventors to collaborate and facilitates knowledge transfer and recombination, which in turn result in more path-breaking innovation.[5]

[4]In an earlier version of the paper, we attempted to differentiate between these two effects, by using data on patent-inventor pairs and adding inventor fixed effects, which effectively control for time-invariant inventor capability. However, this approach fails to account for heterogeneity in capability across collaborating inventors (relative to the focal inventor as captured by inventor fixed effects). We leave this endeavor to future research.

[5]There are other innovation-related benefits and costs that our empirical design fails to capture. First, one important dimension of knowledge transfer from target inventors to their acquirers is the diffusion of tacit knowledge to acquirers' incumbent and newly hired inventors. Through collaborative research, social interaction, and mentoring, target inventors may impact the innovation capabilities of their acquirers more broadly than reported in our paper (via collaboration to produce patents). Second, the very acquisition itself may attract new inventors to the merged firm in order for them to collaborate with target inventors. Offsetting these benefits, the very acquisition could also prompt departure of some of acquirer inventors.

Next, we explore how collaboration and inventor characteristics together are associated with path-breaking innovation.

B. Collaboration, Inventor Characteristics, and Path-Breaking Innovation

Table IA1 in the Supplementary Material examines which inventor characteristics are more conducive to forming collaboration between acquirer and target inventors. We first show that a target inventor and an acquirer inventor are more likely to form a hybrid team if they share the same core area, or are geographically proximate. Our inventor-level finding is consistent with the firm-level evidence in Phene et al. (2012) and Bena and Li (2014), and supports the that is that common ground is necessary for collaboration and knowledge transfer (Cohen and Levinthal (1990), Kogut and Zander (1992)).[6] Given that geographic proximity facilitates forming a social community (e.g., a group or network), learning, and mentoring, we expect that post-merger collaboration will foster tacit knowledge transfer.

Panel A of Table 4 further shows that a target inventor is more likely to join a hybrid team if her significant collaborators are not staying in the merged firm, she is a star inventor, she has a larger network, and she is less specialized. To the extent that star inventors and inventors with larger networks are more capable, our findings suggest that M&As allow acquirers to tap into opportunities for collaboration with such target inventors who would otherwise be inaccessible or unavailable. Panel B of Table 4 shows that an acquirer inventor is more likely to join a hybrid team if she has a larger network, and if she is less specialized.

Next, we shed light on what type of target/acquirer inventors are more productive on collaborative teams. Panel A of Table 4 presents the target inventor-level OLS regression results where the dependent variable is the number of radical patents.[7]

We show that across all specifications, target inventors on hybrid teams are associated with more radical patents (except for column 3). More importantly, we show that target star inventors on hybrid teams are associated with significantly more radical patents. The coefficient on the interaction term HYBRID_TEAM × STAR_INVENTOR is positive and significant at the 5% level. In terms of economic significance, a target star inventor on a hybrid team is associated with 0.265 more radical patents than a target average inventor on a hybrid team, which is nontrivial given that the average number of radical patents per inventor is 0.082. This finding again highlights that M&As offer acquirer inventors collaboration opportunities they would otherwise not have.

Panel B of Table 4 presents the acquirer inventor-level results. We show that across the board, acquirer inventors on hybrid teams are associated with more

[6]It is worth noting that the variable SAME_CORE used in our analysis only captures common ground (based on technology classes, i.e., codified knowledge) on which to build a collaborative relationship. An inventor's knowledge domains and experience, most of which is tacit in nature, equal more than the technology classes in which she produces patents. For example, acquirer and target inventors working for different firms could possess very different knowledge and innovation experience in the form of tacit knowledge, even when their expertise is categorized as in the same technology class.

[7]Table IA2 (IA3) in the Supplementary Material presents the results when the dependent variable is the number of impactful (valuable) patents. Our main findings remain.

TABLE 4

Collaboration, Inventor Characteristics, and Radical Innovation

Table 4 examines how collaboration between acquirer and target inventors and inventor characteristics together are associated with radical innovation over the period *cyr* + 1 to *cyr* + 5. The dependent variable is the number of radical patents. In Panel A, the sample consists of 4,257 target inventors who have applied for at least 1 patent over the period *cyr* + 1 to *cyr* + 5. In Panel B, the sample consists of 28,166 acquirer inventors who have applied for at least 1 patent over the period *cyr* + 1 to *cyr* + 5. Detailed variable definitions are provided in the Appendix. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

	#RADICAL_PATENTS			
	1	2	3	4
Panel A. Collaboration, Target Inventor Characteristics, and Radical Innovation				
ON_HYBRID_TEAM	0.181***	0.174***	0.148	0.360***
	(0.043)	(0.035)	(0.100)	(0.131)
INVENTOR_SIGNIFICANT_CO-INVENTOR_STAY	−0.009			
	(0.023)			
ON_HYBRID_TEAM × INVENTOR_SIGNIFICANT_CO-INVENTOR_STAY	0.051			
	(0.062)			
STAR_INVENTOR		−0.001		
		(0.072)		
ON_HYBRID_TEAM × STAR_INVENTOR		0.265**		
		(0.128)		
INVENTOR_NETWORK_SIZE			0.033***	
			(0.013)	
ON_HYBRID_TEAM × INVENTOR_NETWORK_SIZE			0.013	
			(0.029)	
INVENTOR_SPECIALIZATION				−0.218***
				(0.084)
ON_HYBRID_TEAM × INVENTOR_SPECIALIZATION				−0.306
				(0.212)
No. of obs.	4,257	4,257	4,257	4,257
Adj. R^2	0.187	0.192	0.190	0.193
Panel B. Collaboration, Acquirer Inventor Characteristics, and Radical Innovation				
ON_HYBRID_TEAM	0.257***	0.216***	0.086	0.664***
	(0.063)	(0.043)	(0.096)	(0.228)
INVENTOR_SIGNIFICANT_CO-INVENTOR_STAY	0.002			
	(0.008)			
ON_HYBRID_TEAM × INVENTOR_SIGNIFICANT_CO-INVENTOR_STAY	0.079			
	(0.092)			
STAR_INVENTOR		0.143***		
		(0.029)		
ON_HYBRID_TEAM × STAR_INVENTOR		0.533		
		(0.401)		
INVENTOR_NETWORK_SIZE			0.025***	
			(0.004)	
ON_HYBRID_TEAM × INVENTOR_NETWORK_SIZE			0.052	
			(0.040)	
INVENTOR_SPECIALIZATION				−0.172***
				(0.035)
ON_HYBRID_TEAM × INVENTOR_SPECIALIZATION				−0.721**
				(0.314)
No. of obs.	28,166	28,166	28,166	28,166
Adj. R^2	0.044	0.057	0.049	0.050

radical patents (except for column 3). More importantly, we show that acquirer specialist inventors on hybrid teams are associated with significantly fewer radical patents. The coefficient on the interaction term HYBRID_TEAM × INVENTOR_SPECIALIZATION is negative and significant at the 5% level. In terms of

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economic significance, an increase in acquirer inventor specialization by 1-standard-deviation (0.175) is associated with a drop of 0.126 radical patents, which is again nontrivial given that the average number of radical patents per inventor is 0.082.

Overall, Table 4 shows that target star inventors and acquirer generalist inventors tend to outperform when working collaboratively with their counterparts on a hybrid team.

In summary, we show inter-firm inventor collaboration is associated with more path-breaking innovation relative to intra-firm inventor teams. We next explore other benefits of M&As and the extent to which they contribute to path-breaking innovation.

V. Other Benefits of M&As

In addition to the opportunities to collaborate with target inventors, M&As offer two other well-known benefits that help improve acquirers' innovation performance: access to target inventors' patenting output and knowledge spillovers from target firms (Holmström and Roberts (1998), Ahuja and Katila (2001)). In this section, we explore these two benefits to shed light on the key source of human capital synergies.

A. Acquiring Target Talent

The fact that post-merger, acquirers have target inventors working for them begs the question: is hiring target inventors sufficient on its own to produce path-breaking innovation? We answer this question by first comparing acquirer and target inventors' patenting performance and then accounting for whether they are on a hybrid team or not. Table 5 presents the OLS regression results where the dependent variables are the number of radical/impactful/valuable patents. The baseline case is the number of radical/impactful/valuable patents produced by acquirer inventors post-merger.

Columns 1–3 present the results without accounting for collaboration between acquirer and target inventors. We show that compared to acquirer inventors, target inventors are associated with more radical and valuable patents. Moreover, we show that star inventors, inventors with large networks, and less specialized inventors are associated with more path-breaking innovation. To assess whether target inventors produce more path-breaking innovation on their own or in collaboration with acquirer inventors, we add the indicator variable, ON_HYBRID_TEAM, and the interaction term TARGET_INVENTOR × ON_HYBRID_TEAM. Columns 4–6 present the results.

We show that the coefficient on the indicator variable, ON_HYBRID_TEAM, is positive and significant at the 1% level across all three specifications, suggesting that inter-firm inventor collaboration produces significantly more radical/impactful/valuable patents than those by intra-firm inventor teams. In stark contrast to columns 1–3, we show that after accounting for inter-firm inventor collaboration, the coefficient on TARGET_INVENTOR becomes insignificant, suggesting that target inventors alone are no more productive in path-breaking innovation than their

TABLE 5

Collaboration, Target Inventors Alone, and Path-Breaking Innovation

Table 5 compares collaboration between acquirer and target inventors and target inventors alone in producing path-breaking innovation. The sample consists of 4,257 target inventors and 28,166 acquirer inventors who have applied for at least 1 patent in the target classes over the period *cyr* + 1 to *cyr* + 5. The dependent variables are the number of radical/impactful/valuable patents. The baseline case is the number of radical/impactful/valuable patents by acquirer inventors alone. Detailed variable definitions are provided in the Appendix. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

	#RADICAL_ PATENTS	#IMPACTFUL_ PATENTS	#VALUABLE_ PATENTS	#RADICAL_ PATENTS	#IMPACTFUL_ PATENTS	#VALUABLE_ PATENTS
	1	2	3	4	5	6
TARGET_INVENTOR	0.049*	−0.009	0.078***	0.020	−0.013	0.022
	(0.029)	(0.021)	(0.026)	(0.032)	(0.028)	(0.030)
ON_HYBRID_TEAM				0.277***	0.255***	0.200***
				(0.081)	(0.060)	(0.066)
TARGET_INVENTOR × ON_ HYBRID_TEAM				−0.105*	−0.150**	0.006
				(0.060)	(0.059)	(0.051)
INVENTOR_SIGNIFICANT_ CO-INVENTOR_STAY	0.014	−0.006	−0.023**	0.018*	−0.002	−0.019*
	(0.011)	(0.009)	(0.011)	(0.011)	(0.009)	(0.010)
STAR_INVENTOR	0.150***	0.222***	0.097***	0.147***	0.219***	0.095***
	(0.028)	(0.042)	(0.023)	(0.028)	(0.041)	(0.023)
INVENTOR_NETWORK_SIZE	0.012***	0.017***	0.020***	0.009*	0.015***	0.017***
	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
INVENTOR_SPECIALIZATION	−0.155***	−0.050	−0.095**	−0.154***	−0.048	−0.094**
	(0.040)	(0.041)	(0.047)	(0.040)	(0.041)	(0.046)
No. of obs.	32,423	32,423	32,423	32,423	32,423	32,423
Adj. R^2	0.055	0.064	0.210	0.065	0.070	0.217

acquirer peers. This result is an important finding in the M&A literature (i.e., the benefit of M&As in expanding acquirers' innovation capabilities comes from collaboration between acquirer and target inventors rather than from hiring target inventors alone).

Finally, we show that the coefficient on the interaction term TARGET_ INVENTOR × ON_HYBRID_TEAM is negative and significant in two out of three specifications, suggesting that compared to the positive association between hybrid teams and acquirer inventors' productivity, the positive association between hybrid teams and target inventors' productivity is less pronounced in terms of the number of radical or impactful patents. The negative interaction term shows that the benefit of collaboration in producing path-breaking innovation is not symmetric; acquirer inventors on hybrid teams experience greater increases in productivity than target inventors do.[8]

Considering our results as a whole, we conclude that collaboration between acquirer and target inventors within expanded firm boundaries is key to achieving human capital synergies, rather than gaining access to target talent alone. Moreover, the positive association between being on hybrid teams and path-breaking innovation is stronger for acquirer inventors than for target inventors, indicative of binding constraints on collaboration for acquirer inventors prior to deal completion.

[8]It is worth noting that using a subsample of target star inventors and acquirer inventors, we find that compared to acquirer inventors, target star inventors are associated with more valuable patents, and that after controlling for collaboration, target star inventors alone are not significantly associated with more path-breaking innovation. Moreover, we find that target star inventors on hybrid teams are associated with a similar level of path-breaking innovation as acquirer inventors on hybrid teams.

B. Codified Knowledge Spillovers

As noted above, M&As facilitate acquirer and target inventors gaining access to each other's respective knowledge domains. Following Ahuja and Katila (2001), we measure a firm's knowledge domain as the sum of its portfolio of patents and citations made by those patents over the 5-year period ending the year before deal completion (i.e., year $cyr - 1$). Bena and Li (2014) find that M&As are more likely to take place between firm-pairs that share common knowledge domains. Thus, gaining access to a merger partner's codified knowledge (i.e., patent filings) could be an alternative means to produce path-breaking innovation. Motivated by Bena and Li's study, we introduce three indicator variables to capture citing a common knowledge domain, citing the target's exclusive knowledge domain (i.e., nonoverlapping with that of its acquirer), and citing the acquirer's exclusive knowledge domain (i.e., nonoverlapping with that of its target firm). Table 6 presents the linear probability regression results where the dependent variables are indicator variables for radical/impactful/valuable patents.

TABLE 6

Codified Knowledge Spillovers and Path-Breaking Innovation

Table 6 examines the relation between codified knowledge spillovers and path-breaking innovation over the period $cyr + 1$ to $cyr + 5$. The dependent variables are the indicator variables for radical, impactful, and valuable patents. In Panel A, the sample consists of patents applied for by either acquirer inventor-only teams or hybrid teams. In Panel B, the sample consists of patents applied for by either target inventor-only teams or hybrid teams. Detailed variable definitions are provided in the Appendix. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

	RADICAL	IMPACTFUL	VALUABLE
	1	2	3
Panel A. Codified Knowledge Spillovers From Target Firms to Acquirer Inventors and Path-Breaking Innovation			
HYBRID_TEAM	0.025**	0.011*	0.011
	(0.010)	(0.006)	(0.007)
CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE	0.016	−0.001	−0.009
	(0.017)	(0.010)	(0.012)
CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE	0.028***	0.010**	0.002
	(0.004)	(0.004)	(0.003)
CITING_COMMON_KNOWLEDGE	0.068***	0.015***	0.006
	(0.009)	(0.005)	(0.010)
#INVENTORS	0.010**	0.022***	−0.007**
	(0.004)	(0.004)	(0.004)
No. of obs.	45,350	45,350	45,350
Adj. R^2	0.041	0.069	0.145
Panel B. Codified Knowledge Spillovers From Acquirers to Target Inventors and Path-Breaking Innovation			
HYBRID_TEAM	0.012	0.003	−0.002
	(0.009)	(0.002)	(0.003)
CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE	0.017	−0.004*	−0.008*
	(0.014)	(0.002)	(0.005)
CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE	0.010	−0.002	−0.001
	(0.008)	(0.002)	(0.003)
CITING_COMMON_KNOWLEDGE	0.063***	0.001	0.0001
	(0.012)	(0.002)	(0.003)
#INVENTORS	0.008	−0.001	0.002
	(0.007)	(0.002)	(0.004)
No. of obs.	8,675	8,675	8,675
Adj. R^2	0.092	0.056	0.026

Panel A of Table 6 compares patenting output by acquirer inventor-only teams and hybrid teams, focusing on the role of codified knowledge spillovers from target firms to acquirer inventors. We show that the coefficient on CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE is not significantly different from 0, suggesting no significant benefits from codified knowledge spillovers from target firms to acquirer inventors in terms of producing path-breaking innovation. In contrast, we show that both CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE and CITING_COMMON_KNOWLEDGE are positively and significantly associated with the likelihood of a patent being radical and impactful, suggesting that the acquirer's knowledge base drives path-breaking innovation post-merger. Finally, we show that compared to acquirer inventor-only teams, hybrid teams are positively and significantly associated with the likelihood of a patent being radical and impactful.

Panel B of Table 6 compares patenting output by target inventor-only teams and hybrid teams, focusing on the role of codified knowledge spillovers from acquirers to target inventors. We show that the coefficient on CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE is not significantly different from 0, suggesting no significant benefits from codified knowledge spillovers from acquirers to target inventors in terms of producing path-breaking innovation. In contrast, we show that CITING_COMMON_KNOWLEDGE is positively and significantly associated with the likelihood of a patent being radical.

To the extent that common knowledge captures complementary assets between the acquirer and its target firm, our findings in Table 6 support the prediction of property rights theory (Grossman and Hart (1986), Hart and Moore (1990), and Rhodes-Kropf and Robinson (2008)) that in a world with incomplete contracting, synergies are realized when complementary assets are placed under common ownership.

In summary, we find that codified knowledge spillovers from target firms to acquirer inventors (or from acquirers to target inventors) do not contribute to path-breaking innovation.

C. Codified Knowledge Spillovers via Collaboration

The literature on knowledge spillovers recognizes that state-of-the-art technologies are often tacit and embodied in the human capital of a firm's employees, such that they cannot easily be transferred across firms (Winter (1987), Cohen and Levinthal (1990), Leonard-Barton (1995), and Song et al. (2003)). While collaboration facilitates both spillovers of codified knowledge and transfers of tacit knowledge, it is essential in the latter, because transfers of tacit knowledge occur within social communities, and through learning and mentoring (Lucas and Moll (2014)). In contrast, spillovers of codified knowledge can take place without social interaction/collaboration (e.g., via reading patent filings). By expanding firm boundaries, M&As facilitate social interactions between acquirer and target inventors and hence are likely to have a greater effect on transfers of tacit knowledge than on spillovers of codified knowledge.

As shown above, spillovers of codified knowledge from target firms to acquirer inventors (or from acquirers to target inventors) are not associated with path-breaking innovation. However, spillovers of codified knowledge could still be a channel through which collaboration between acquirer and target inventors is positively associated with path-breaking innovation (i.e., inter-firm inventor collaboration fosters path-breaking innovation by facilitating spillovers of codified knowledge). In order to assess the possibility that spillovers of codified knowledge are behind the positive association between hybrid teams and path-breaking innovation, we give spillovers of codified knowledge its best shot. That is, in the case when a patent filed by acquirer (target) inventors clearly relies on its target's (acquirer's) exclusive knowledge domain and hence there are potential benefits from codified knowledge spillovers in terms of producing path-breaking innovation, we examine whether the positive association between inter-firm inventor collaboration and path-breaking innovation is strengthened. If the positive association is not getting stronger for such innovation, it would be safe for us to infer that spillover of codified knowledge is not the main mechanism underlying the positive association between collaboration and path-breaking innovation. This analysis thus allows us to determine to what extent the positive association between collaboration and path-breaking innovation is due to the former facilitating spillovers of codified knowledge. Table 7 extends the analysis in Table 6 by adding an interaction term

TABLE 7

Codified Knowledge Spillovers via Collaboration and Path-Breaking Innovation

Table 7 examines whether codified knowledge spillovers via collaboration are associated with path-breaking innovation over the period *cyr* + 1 to *cyr* + 5. The dependent variables are the indicator variables for radical, impactful, and valuable patents. In Panel A, the sample consists of patents applied for by either acquirer inventor-only teams or hybrid teams. In Panel B, the sample consists of patents applied for by either target inventor-only teams or hybrid teams. Detailed variable definitions are provided in the Appendix. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

	RADICAL	IMPACTFUL	VALUABLE
	1	2	3
Panel A. Codified Knowledge Spillovers via Collaboration from Target Firms to Acquirer Inventors and Path-Breaking Innovation			
HYBRID_TEAM	0.026**	0.013*	0.011
	(0.011)	(0.007)	(0.008)
CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE	−0.014	0.004	−0.015
	(0.015)	(0.014)	(0.014)
HYBRID_TEAM × CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE	0.018	−0.043*	0.012
	(0.039)	(0.023)	(0.031)
#INVENTORS	0.010**	0.022***	−0.007**
	(0.004)	(0.004)	(0.004)
No. of obs.	45,350	45,350	45,350
Adj. R^2	0.034	0.068	0.145
Panel B. Codified Knowledge Spillovers via Collaboration from Acquirers to Target Inventors and Path-Breaking Innovation			
HYBRID_TEAM	0.017	0.017	−0.027**
	(0.011)	(0.011)	(0.013)
CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE	−0.017	0.003	−0.007
	(0.016)	(0.009)	(0.010)
HYBRID_TEAM × CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE	−0.003	0.0002	0.007
	(0.008)	(0.018)	(0.014)
#INVENTORS	0.010	0.006	−0.007
	(0.007)	(0.007)	(0.012)
No. of obs.	8,675	8,675	8,675
Adj. R^2	0.087	0.070	0.197

between hybrid teams and the indicator variable for citing a merger partner's exclusive knowledge domain.

Panel A of Table 7 compares patenting output by acquirer inventor-only teams and hybrid teams, focusing on spillovers of codified knowledge via collaboration between acquirer and target inventors. The variables of interest are CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE and HYBRID_TEAM × CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE. We show that the coefficient on CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE is not statistically different from 0, and the coefficient on the interaction term is negative and significant when the dependent variable is the number of impactful patents, suggesting that codified knowledge spillovers via collaboration are negatively associated with impactful innovation.

Panel B of Table 7 compares patenting output by target inventor-only teams and hybrid teams, focusing on spillovers of codified knowledge via collaboration between acquirer and target inventors. The variables of interest are CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE and HYBRID_TEAM × CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE. We show that the coefficient on neither variable is statistically different from 0 across all three specifications, suggesting that codified knowledge spillovers alone or via collaboration are not significantly associated with path-breaking innovation.

Overall, Tables 6 and 7 show that spillovers of codified knowledge between merger partners, either alone or via hybrid teams, are not significantly associated with path-breaking innovation. These findings thus provide suggestive evidence that it is the transfer of the other type of knowledge (tacit knowledge embodied in the human capital of inventors) via collaboration that results in path-breaking innovation. As far as we are aware, we are the first in the innovation literature to make an attempt to differentiate the roles of these two types of knowledge capital in producing path-breaking innovation.

In summary, we conclude that recombining tacit knowledge embodied in the human capital of acquirer and target inventors is likely the mechanism underlying the path-breaking innovation by inter-firm inventor teams.

VI. Deal-Level Evidence

In this section, we employ deal-level data to help establish the counterfactual, that is, what would have been the innovation output of inventors of the acquirer-target pairs either on a hybrid term or not had there been no merger.

Figure 1 presents the frequency of collaboration between acquirer and target inventors over time for our sample of 942 completed deals. We show that there is a steep increase in the frequency of collaboration post-merger, suggesting that there had been a binding constraint for collaboration and knowledge transfer inside the acquirer pre-merger.

To illustrate the counterfactual, we employ a control sample of matched pairs that have similar characteristics and a similar estimated likelihood of merging, but that do not merge. We employ a propensity score matching (PSM) method based on firm size, M/B, and the number of patents over the 5-year period prior to deal announcement and require both an event firm (either an acquirer or a target firm)

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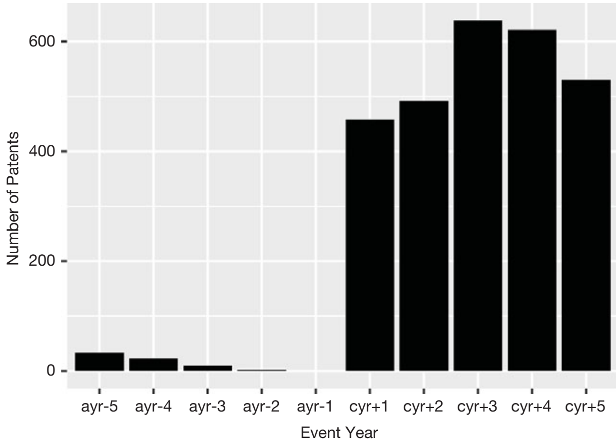
FIGURE 1

Frequency of Collaboration Between Acquirer and Target Inventors over Time

Figure 1 shows across sample deals the total number of patents by collaboration between acquirer and target inventors over the period *ayr* − 5 to *ayr* − 1 and the period *cyr* + 1 and *cyr* + 5. Acquirer (target) inventors are inventors who work at the acquirer (target firm) in *ayr* − 1. Our sample consists of 942 deals announced and completed over the period of 1981 to 2012.



and its control firms to have the same core technology class. We keep up to 5 control firms for each event firm based on their propensity scores, and end up with 2 sets of control firms: 2,707 acquirer control firms and 942 target control firms. Table 8 presents the results.

In Panel A of Table 8, we examine the extent of collaboration between acquirer and target inventors after deal completion relative to that between matched pairs. Column 1 employs a subset of the 942 completed deals (i.e., 650 deals whose acquirers have matched control firms based on their propensity scores). Column 2 employs the sample of 650 acquirer-target pairs and 2,707 acquirer control-target pairs. Column 3 employs a subset of the 942 completed deals (i.e., 228 deals whose target firms have matched control firms based on their propensity scores). Column 4 employs the sample of 228 acquirer-target pairs and 942 acquirer-target control pairs. We show a significant increase in the frequency of collaboration between acquirer and target inventors after deal completion compared to that between acquirer control and target inventors (acquirer and target control inventors), as captured by the coefficient on the interaction term AFTER × SAMPLE. In terms of economic significance, compared to the number of hybrid teams formed in acquirer control-target (acquirer-target control) pairs post-merger, the number of hybrid teams formed in acquirer-target pairs post-merger on average is 0.815 (1.713) more per pair-year. In untabulated analysis, we find that the frequency of collaboration between acquirer control inventors and target inventors is low, at about 0.1 per pair-year, and the frequency of collaboration between acquirer inventors and target control inventors is 0, consistent with our conjecture that collaboration without common ownership is in reality highly unlikely.

In Panel B of Table 8, we examine whether there is a significant increase in path-breaking innovation by hybrid teams of acquirer-target pairs after deal

TABLE 8

Increase in Collaboration and Path-Breaking Innovation After Deal Completion: Using Matched Pairs as Benchmark

Table 8 examines, at the deal level, how the frequency of collaboration between acquirer and target inventors and the number of path-breaking patents change after deal completion. We employ a PSM method based on firm size, M/B, and the number of patents over the 5-year period prior to deal announcement and require both an event firm (either an acquirer or a target firm) and its control firms to have the same core technology class. We keep up to 5 control firms for each event firm based on their propensity scores. In Panel A, we examine the extent of collaboration between acquirer and target inventors after deal completion relative to that between matched pairs. The dependent variable is the number of patents in the target classes applied for by hybrid teams consisting of both acquirer (acquirer control) and target (target control) inventors. Column 1 employs a subset of the 942 completed deals (i.e., 650 deals whose acquirers have matched control firms based on their propensity scores). Column 2 employs the sample of 650 acquirer-target pairs and 2,707 acquirer control-target pairs. Column 3 employs a subset of the 942 completed deals (i.e., 228 deals whose target firms have matched control firms based on their propensity scores). Column 4 employs the sample of 228 acquirer-target pairs and 942 acquirer-target control pairs. AFTER is an indicator variable that takes the value of 1 over the period *cyr* + 1 to *cyr* + 5, and 0 over the period *ayr* − 5 to *ayr* − 1. SAMPLE is an indicator variable that takes the value of 1 for the acquirer-target pairs, 0 for the matched pairs. In Panel B (C), we examine whether there is a significant increase in path-breaking innovation by hybrid teams of acquirer-target pairs after deal competition compared to that by hybrid teams of acquirer control-target (acquirer-target control) pairs. The dependent variable is the number of path-breaking patents in the target classes in the deal-year scaled by the value of the deal (in 2019 dollar). Detailed variable definitions are provided in the Appendix. All models control for deal fixed effects. Robust standard errors clustered at the deal level are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Panel A. Deal-Level Frequency of Collaboration Between Acquirer and Target Inventors

	#Patents by Hybrid Teams			
	1	2	3	4
AFTER	0.778***	−0.007	1.625***	−0.017
	(0.180)	(0.005)	(0.479)	(0.016)
AFTER × SAMPLE		0.815***		1.713***
		(0.203)		(0.548)
No. of obs.	6,500	33,570	2,280	11,700
Adj. R^2	0.474	0.089	0.489	0.105

	#RADICAL_PATENTS	#IMPACTFUL_PATENTS	#VALUABLE_PATENTS	#RADICAL_PATENTS	#IMPACTFUL_PATENTS	#VALUABLE_PATENTS
	1	2	3	4	5	6
Panel B. Deal-Level Path-Breaking Innovation: Using the Sample of 650 Acquirer-Target Pairs and 2,707 Acquirer Control-Target Pairs						
AFTER	−1.377**	−1.244***	−0.385***	−1.377**	−1.243***	−0.384***
	(0.539)	(0.398)	(0.075)	(0.539)	(0.397)	(0.075)
AFTER × SAMPLE	0.699***	0.621***	0.497***	0.277***	0.242**	0.310***
	(0.123)	(0.145)	(0.118)	(0.101)	(0.096)	(0.103)
AFTER × SAMPLE × #HYBRID_TEAMS				0.852***	0.766**	0.378**
				(0.246)	(0.318)	(0.149)
No. of obs.	33,570	33,570	33,570	33,570	33,570	33,570
Adj. R^2	0.592	0.588	0.413	0.592	0.589	0.413
Panel C. Deal-Level Path-Breaking Innovation: Using the Sample of 228 Acquirer-Target Pairs and 942 Acquirer-Target Control Pairs						
AFTER	−0.618	−0.530	0.413	−0.618	−0.530	0.413
	(0.423)	(0.496)	(0.480)	(0.423)	(0.496)	(0.481)
AFTER × SAMPLE	−1.216***	−1.112***	−1.418**	−1.772***	−1.498***	−1.491**
	(0.280)	(0.415)	(0.556)	(0.408)	(0.504)	(0.670)
AFTER × SAMPLE × #HYBRID_TEAMS				0.713***	0.494***	0.094
				(0.220)	(0.172)	(0.239)
No. of obs.	11,700	11,700	11,700	11,700	11,700	11,700
Adj. R^2	0.293	0.300	0.242	0.293	0.300	0.242

completion compared to that by hybrid teams of acquirer control-target pairs, as captured by the triple interaction term AFTER × SAMPLE × #HYBRID_TEAMS. Using all three measures of path-breaking innovation, we show that the coefficient on the triple interaction term is positive and significant, suggesting more path-breaking innovation within merging firm pairs than within matched pairs. In terms of economic significance, compared to the increase in the number of radical/impactful/valuable patents by hybrid teams in acquirer control-target pairs from pre- to post-merger, the increase by hybrid teams in acquirer-target pairs is on average 0.852/0.766/0.378 more per pair-year.

In Panel C of Table 8, we examine whether there is a significant increase in path-breaking innovation by hybrid teams of acquirer-target pairs after deal competition compared to that by hybrid teams of acquirer-target control pairs. Again, using all three measures of path-breaking innovation, we show that the coefficient on the triple interaction term is positive and significant (with one exception, when the measure of path-breaking innovation is the number of valuable patents), suggesting more path-breaking innovation within merging firm pairs than within matched pairs. In terms of economic significance, compared to the increase in the number of radical/impactful patents by hybrid teams in acquirer-target control pairs from pre- to post-merger, the increase by hybrid teams in acquirer-target pairs is on average 0.713/0.494 more per pair-year.

In Panel A of Table IA4 in the Supplementary Material, we examine whether star inventors in acquirer-target pairs are more likely to join hybrid teams compared to those in matched pairs. Column 1 employs a sample of target inventors in acquirer-target pairs and acquirer-target control pairs. Column 2 employs a sample of acquirer inventors in acquirer-target pairs and acquirer control-target firm pairs. The dependent variable is the indicator variable ON_HYBRID_TEAM. We show that across both columns, the coefficient on the interaction term STAR_INVENTOR × SAMPLE is positive and significant, suggesting that target (acquirer) star inventors in acquirer-target pairs are more likely to join hybrid teams compared to their counterparts in matched pairs. In Panel B (C), we examine whether target (acquirer) star inventors in acquirer-target pairs are more productive compared to their counterparts in acquirer-target control pairs (acquirer control-target pairs). We show that across both panels, the coefficient on the interaction term STAR_INVENTOR × SAMPLE is negative and significant in 4 out of the 6 specifications, suggesting that star inventors in acquirer-target pairs are no more productive than their counterparts in matched pairs. We conclude that it is hybrid teams, rather than star inventors, that contribute to path-breaking innovation.

In summary, using propensity score-matched control firms as a benchmark, we show that acquirer (target) inventors on hybrid teams significantly outperform their counterparts in matched pairs, suggesting the importance of M&As in fostering inter-firm collaboration and producing path-breaking innovation.[9]

VII. Conclusions

Using a large and novel data set tracking inventors' career paths over the period of 1976 to 2019, we provide new evidence on whether and how acquirers achieve human capital synergies post-merger.

[9]To disentangle selection from the treatment effect of M&As, we exploit a quasi-experiment in which the control group is a sample of failed bids for reasons unrelated to innovation (Bena and Li (2014), Seru (2014)). See Appendix IA2 and Table IA5 in the Supplementary Material for details.

We show that collaboration between acquirer and target inventors is associated with more radical, impactful, and valuable patents than those filed by either acquirer or target inventor-only teams. We further show that collaboration between acquirer and target inventors is more important to improving acquirers' innovation capabilities than hiring target inventors alone and spillovers of codified knowledge. Moreover, we uncover that recombining tacit knowledge embodied in the human capital of acquirer and target inventors is likely the mechanism for the positive association between hybrid teams and path-breaking innovation. Finally, using a control sample of matched pairs and difference-in-differences specifications to establish the counterfactual, we confirm our main thesis that only M&As result in meaningful and productive inter-firm inventor collaboration.

We conclude that post-merger inter-firm inventor collaboration is one key means for achieving human capital synergies.

Appendix. Variable Definitions

All firm characteristics are measured at the fiscal year end before bid announcement. All dollar values are in 2019 dollars.

Inventor-Level Patenting Performance Measures

#RADICAL_PATENTS: The number of an inventor's radical patents applied for over the period from 1 year after deal completion ($cyr + 1$) to 5 years after ($cyr + 5$). A patent is radical if it draws on knowledge that has never or rarely been used before by inventors in the same field (Eggers and Kaul (2018)). In this article, we define radical patents as those in the top 5th percentile in terms of drawing on fundamentally new knowledge among granted patents in the same technology class-year.

#IMPACTFUL_PATENTS: The number of an inventor's impactful patents applied for over the period $cyr + 1$ to $cyr + 5$. A patent is impactful if its number of citations (received up to 2019) is in the top 5th percentile among granted patents in the same technology class-year.

#VALUABLE_PATENTS: The number of an inventor's valuable patents applied for over the period $cyr + 1$ to $cyr + 5$. A patent is valuable if its value using Kogan et al.'s (2017) measure is in the top 5th percentile among granted patents in the same technology class-year.

Inventor Characteristics

TARGET_INVENTOR: An indicator variable that takes the value of 1 if an inventor is working at the target firm in the year before bid announcement ($ayr - 1$), and 0 otherwise.

ON_HYBRID_TEAM: An indicator variable that takes the value of 1 if an inventor is on at least 1 hybrid team over the period $cyr + 1$ to $cyr + 5$, and 0 otherwise.

INVENTOR_SIGNIFICANT_COINVENTOR_STAY: An indicator variable that takes the value of 1 if at least one significant coinventor works for the merged firm over the period $cyr+1$ to $cyr+5$, and 0 otherwise. A significant co-inventor is a collaborator to a focal inventor whose number of jointly developed patents with the focal inventor is more than 50% of the latter's total number of patents over the period $ayr-5$ to $ayr-1$.

STAR_INVENTOR: An indicator variable that takes the value of 1 if an inventor's number of citations received (up to 2019) for granted patents applied for up to $ayr-1$ is in the top 5th percentile among all inventors in the PatentsView database, and 0 otherwise.

INVENTOR_NETWORK_SIZE: The natural logarithm of 1 plus the number of unique inventors who have collaborative links of no more than 2 teams away from the focal inventor up to $ayr-1$.

INVENTOR_SPECIALIZATION: The Herfindahl index based on the technology class-share of granted patents applied for by an inventor up to $ayr-1$. The bigger this value is, the more specialized the inventor is in terms of her patenting output.

#PATENTS: The number of granted patents applied for by an inventor up to $ayr-1$.

#CITATION-WEIGHTED_PATENTS: The total number of citations received over the 5-year period since the grant date of an inventor's patents applied for up to $ayr-1$.

Inventor-Pair Characteristics

SAME_CORE: An indicator variable that takes the value of 1 if 2 inventors share the same core technology class, and 0 otherwise. An inventor's core class is the technology class in which she has been granted the most number of patents applied for up to $ayr-1$.

Patent Characteristics

RADICAL: An indicator variable that takes the value of 1 if a patent is radical, and 0 otherwise. A patent is radical if it draws on knowledge that has never or rarely been used before by inventors in the same field (Eggers and Kaul (2018)). In this article, we define radical patents as those in the top 5th percentile in terms of drawing on fundamentally new knowledge among granted patents in the same technology class-year.

IMPACTFUL: An indicator variable that takes the value of 1 if a patent is impactful, and 0 otherwise. A patent is impactful if its number of citations (received up to 2019) is in the top 5th percentile among granted patents in the same technology class-year.

VALUABLE: An indicator variable that takes the value of 1 if a patent is valuable, and 0 otherwise. A patent is valuable if its value using Kogan et al.'s (2017) measure is in the top 5th percentile among granted patents in the same technology class-year.

ACQUIRER_INVENTOR-ONLY_TEAM: An indicator variable that takes the value of 1 if inventors of a patent do not include any target inventor, but include at least 1 acquirer inventor, and 0 otherwise.

TARGET_INVENTOR-ONLY_TEAM: An indicator variable that takes the value of 1 if inventors of a patent do not include any acquirer inventor, but include at least 1 target inventor, and 0 otherwise.

HYBRID_TEAM: An indicator variable that takes the value of 1 if inventors of a patent include at least 1 target inventor and at least 1 acquirer inventor, and 0 otherwise.

#INVENTORS: The number of inventors behind a patent.

CITING_TARGET'S_EXCLUSIVE_KNOWLEDGE: An indicator variable that takes the value of 1 if a patent cites at least 1 patent in the target firm's knowledge domain that is not overlapping with the acquirer's knowledge domain. Following Ahuja and Katila (2001), a firm's knowledge domain is the sum of its portfolio of patents applied for over the 5-year period up to $cyr - 1$ and citations made by those patents.

CITING_ACQUIRER'S_EXCLUSIVE_KNOWLEDGE: An indicator variable that takes the value of 1 if a patent cites at least 1 patent in the acquirer's knowledge domain that is not overlapping with the target firm's knowledge domain.

CITING_COMMON_KNOWLEDGE: An indicator variable that takes the value of 1 if a patent cites at least 1 patent that is in both the acquirer's and the target firm's knowledge domains.

Deal and Firm Characteristics

#HYBRID_TEAMS: The logarithm of 1 plus the frequency of post-merger collaboration between acquirer and target inventors over the period $cyr + 1$ to $cyr + 5$.

DIVERSIFYING: An indicator variable that takes the value of 1 if the first 2-digit SIC code of an acquirer is different from that of its target firm, and 0 otherwise.

RELATIVE_SIZE: The ratio of transaction value to an acquirer's book value of assets.

ALL_CASH: An indicator variable that takes the value of 1 if a deal is entirely financed by cash, and 0 otherwise.

ALL_STOCK: An indicator variable that takes the value of 1 if a deal is entirely finance by equity, and 0 otherwise.

TOBIN'S_Q: The ratio of market value of assets to book value of assets.

ROA: The ratio of operating income before depreciation to book value of assets.

LEVERAGE: The ratio of total debt to book value of assets.

PRIOR_YEAR_STOCK_RETURN: The cumulative return over the calendar year right before $ayr - 1$.

Supplementary Material

Supplementary Material for this article is available at https://doi.org/10.1017/S0022109022000503.

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