Inventor bricolage and firm technology research and development

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We examine the conditions around firm use of 'inventor bricolage,' or the reconstruction of technological capabilities through reallocation of extant individual inventors to address new opportunities embodied in patents. Empirically, we examine the dynamics of both firm and individual patenting activity in publicly traded Life Science Diagnostic firms to explore how inventor bricolage is related to firms' existing research and development (R&D) capabilities and firms' acquisition of external capabilities through merger and acquisition (M&A) activities. Evidence at the firm level suggests that breadth of inventors' human capital and collaboration with co-researchers with relevant experience is positively related to inventor bricolage. At the inventor level, the fewer patents an inventor has, the broader the individual's prior patent portfolio, and the more co-researchers with relevant experience, the more likely inventors will patent in a new area. M&A does not appear to have an impact on the utilization of existing human capital. Our findings suggest that R&D managers should assign inventors with less assimilative capacity and more creative capacity in teams where there is relevant experience in order to promote inventor bricolage.

1. Introduction

The problem of constructing resources for growth is a critical problem in high-technology firms where technological capabilities determine if a firm can meet their research and development (R&D) strategy (Nelson and Winter, 1982). In entrepreneurial firms the ability to construct R&D capabilities is particularly important because these firms are typically resource constrained (Aldrich, 1999) and/or time constrained (Bourgeois and Eisenhardt, 1988). Faced with these constraints, the standard 'make-or-buy' decision of resource construction (Miles and Snow, 1984) where firms can either develop new capabilities internally or firms can buy new capabilities through external acquisition (Andersson et al., 2008), may not be relevant.

Either strategy (making or buying) can be costly in terms of resources and time. A less costly, potentially faster strategy is to recombine and leverage exiting capabilities in new and innovative ways. This reallocation of capabilities is an important, yet under-studied special case of the 'make-or-buy' literature. Making new capabilities through reallocating and recombining existing resources in innovative ways, or implementing bricolage – where bricolage is 'making do by applying combinations of the resources at hand to new problems and opportunities' (Baker and Nelson, 2005, p. 333) – is a potentially valuable channel for capability development in resource- and time-constrained entrepreneurial firms.

One particular resource that can be reallocated and recombined to address new opportunities is human capital, such as the human capital embedded in the scientists and inventors employed by a firm. Specifically, firms can recombine individuals' sets of capabilities through reallocation of inventors, which we term 'inventor bricolage.' In this paper, we examine under what conditions inventor bricolage is successfully implemented. Additionally, we examine the relationship between inventor bricolage, as an internal source of capabilities, and merger and acquisition (M&A) activity, as an external source of capabilities (Hagedoorn and Duysters, 2002). Organizations typically utilize a variety of approaches to allocate human capital and can take on multiple methods simultaneously (Davis-Blake and Uzzi, 1993; Lepak and Snell, 1999). By separating the allocation of internal sources of human capital and external sources of human capital, we contribute to the understanding of how firms can build R&D capabilities.

The contributions of this study are threefold. First, we add to the micro-foundations of innovation by connecting firm level technology strategies to their use of individual-level resources. We argue that by looking at the individual, we can investigate how inventor bricolage (an internal source of technological capabilities) and M&A (an external source of technological capabilities) are related (or unrelated). Specifically, integration of technological capabilities witnessed in the bricolage of individual knowledge workers is important to understanding M&A as a mechanism for technology R&D. Second, we add to the sparse literature on how firms manage the bricolage of individual knowledge workers. We argue that this is an important tool for entrepreneurial firms where the capabilities of a small set of individuals are recombined to generate innovations under uncertain conditions. Third, we extend the literature on technological entrepreneurship by looking at innovation at the individual level in dynamic environments. The behavior of individuals is important to understanding firm innovation efforts as a key aspect of entrepreneurship research is about understanding the choices and actions of individuals as they interface with larger social entities. In entrepreneurial settings, individuals make decisions under uncertainty (Alvarez and Barney, 2005) individuals recognize opportunities (Shane, 2003), individuals bear risk (Wu and Knott, 2006), individuals bring knowledge and experience to the firm (Shane and Khurana, 2003; Nanda and Sorensen, 2006) and develop entrepreneurship-specific human capital (Campbell, 2007), but these behaviors are all performed in the context of larger social settings. Because understanding the behavior of individuals is critical to entrepreneurial action, we focus on a micro-level entrepreneurial setting where we can isolate the paths of actions at the individual level within a larger context.

The paper is organized as follows. First we review the extant literature on bricolage and the role of individuals in firm innovation. We then develop hypotheses relating inventor bricolage to internal and/or external capabilities in the innovation process. Empirically, we first examine the dynamics of firm-level patenting behavior in publicly traded Life Science Diagnostic firms to explore how internal firm-level capabilities and firms' acquisition of external capabilities through M&A activities influence the reallocation of human capital. We then disaggregate the data and examine individual inventor behavior to examine the role of individuals' existing capabilities in inventor bricolage.

2. Characterizing the nature of inventor bricolage in entrepreneurial firms

The concept of making do with whatever is at hand has been termed 'bricolage.' First introduced by Levi-Strauss (1966), bricolage has been incorporated into the literature on entrepreneurship, largely due to the nature of resource construction, i.e. recombining existing resources, to pursue unique opportunities. Similarly, Kogut and Zander (1992) argue that learning and innovation are functions of firm-level combinative capabilities (i.e., the ability to generate new applications from existing knowledge).

The literature on technological entrepreneurship has developed the concept of bricolage to look at distributed agency in the R&D of technology (Garud and Karnoe, 2003). However, in industries with strong appropriability regimes, this distributed agency is limited within an entrepreneurial firm. Particularly, entrepreneurial firms are often resource constrained (Aldrich, 1999) and/or time constrained (Bourgeois and Eisenhardt, 1988). One resource in entrepreneurial firms that can be reallocated and recombined to address new problems and opportunities is human capital.

In this paper, we focus on the role of 'inventor bricolage' in the technology R&D context. We build on the definition of Baker and Nelson (2005, p. 333) and define *inventor bricolage* as the construction of technological capabilities through recombining the knowledge of inventors on hand to address opportunities. In our conceptualization, inventors will internally develop new technological capabilities needed to pursue a technology R&D strategy by recombining existing skills (i.e., the resources at hand) in new technological areas (i.e., for new purposes).

In addition, to foster inventor bricolage firms are critical in providing inventors with a new context (i.e., firms refuse to enact limitations). Weick (1979) observes that environments are frequently enacted when actors refuse to test the limitations defined by institutional or cultural settings. The converse is true of bricolage: actors must consciously and consistently test conventional limitations (Baker and Nelson, 2005). However, inventors will keep improving technology in a context of use until given a new context (Tyre and Von Hippel, 1997). Thus we assume, in the case of inventor bricolage, that when inventors change their invention patterns it represents decisions that the employing firms have implemented. Furthermore, we suggest that there are certain conditions within firms that foster inventor bricolage. In particular, inventor bricolage will be fostered by entrepreneurial firms that are resource constrained and encourage inventors to try out their skills in untested areas (Garud and Karnoe, 2003). Such firms need to build R&D on existing skills and have less bureaucracy and have less fully formed and constraining job descriptions.

In line with Rothaermel and Hess (2007) we assume innovation lies across different levels of analysis that can have compensating or reinforcing effects on innovative output. We examine the role of inventor bricolage or the construction of technological capabilities through recombination of extant individual inventor's knowledge across patent production to address new opportunities in new technological areas. We argue that inventor bricolage is affected by both worker-embedded capabilities and external capabilities.

3. Inventor bricolage and internal capabilities

In technology R&D, the firm's key resources are the skills embedded in inventors. As a result, inventor bricolage and the conditions that support inventor bricolage are particularly valuable resources to innovative and resource-constrained firms. When investigating the internal capability to reconstruct technological capabilities through reallocation of extant individual inventors, we turn to the concept of absorptive capacity – the 'ability to recognize the value of new external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990). As originally defined, absorptive capacity is a measure of the capabilities of individuals, however, the concept has evolved over time to be primarily viewed as a firm-level measure that indicates the ability for a firm to recognize and exploit external knowledge (Zahra and George, 2002). We return to the original conceptualization of absorptive capacity at the level of the individual and thus contribute to the micro-foundations of innovation.

Specifically, we examine the ability of individuals to recognize and exploit knowledge from external sources. Zahra and George (2002, p. 188) delineate absorptive capacity into three primary dimensions: (1) the ability to value, assimilate, and apply new knowledge; (2) a broad array of skills; and (3) the capability to learn and problem-solve. We examine how each of these dimensions influences the overall absorptive capacity of individual inventors. In particular, we posit that the 'ability to value, assimilate, and apply new knowledge' is related to an individual's assimilative capacity; the possession of a 'broad array of skills' is related to an individual's creative capacity; and the 'capability to learn and problem-solve' is related to the collaborative capacity of individual inventors within the firm. All three of these factors, in turn, influence inventor bricolage. In the next section, we explore these three constructs at the firm level and then establish the micro-foundations of the constructs by looking at how the traits and abilities of individuals support the constructs.

3.1. Assimilative capacity

The first dimension of absorptive capacity is assimilative capability, which we propose will affect the firms' ability to reconstruct technological capabilities through reallocation of extant individual inventors. At the individual level, we refer to assimilative capacity as the ability to value knowledge through past experience and investment. Assimilative capacity, at the firm level, refers to the firm's routines and processes that allow it to analyze, process, interpret, and understand the information obtained from external sources (Szulanski, 1996; Kim, 1997). Ideas and discoveries that fall beyond a firm's (or indivdiual's) search zone are overlooked because the firm cannot easily comprehend them (Cyert and March, 1963; Rosenkopf and Nerkar, 2001).

At the firm level, R&D has been shown to be a good proxy for absorptive capacity because R&D investment allows a firm to stay current with technological trends in the industry and facilitates identification and implementation of necessary external knowledge (Cohen and Levinthal, 1990). At the individual level, prior patents play the same role as R&D does for firms. Prior patenting activity allows the individual to stay at the vanguard of their area of expertize and to more rapidly identify opportunities in their field of specialization.

Similar to Cohen and Levinthal (1990) we argue that this dimension of absorptive capacity will not assist the individual in taking on unique opportunities in and of itself. Although increased patenting efforts indicate an inventor is wiser, they also maybe older and less prone to building on knowledge outside their specialization.

H1: *The probability that an inventor will patent in a new patent class is related negatively to the inventor's number of previous patents.*

3.2. Creative capacity

The second dimension of absorptive capacity that we propose will affect the firms' ability to reconstruct technological capabilities through reallocation of extant individual inventors is creative capacity. Although Cohen and Levinthal (1990) do discuss including diversity of background in an individual's absorptive capacity, we argue that the breadth of an inventor's experience captures the inventor's creative capacity (Gordon, 1961) rather than their assimilative capacity (or depth of experience).

An individual inventor's ability to be on the technological frontier of multiple fields and draw on external knowledge is essential for recognizing opportunity in a new area. Creative capacity measures the ability for an individual to apply their knowledge to areas outside of their specialization. Creative capacity is analogous to assimilative capacity: assimilative capacity measures how well an individual can internalize external knowledge and creative capacity measures how well an individual can externalize internal knowledge.

Thus, one of the necessary conditions for inventor bricolage is breadth of skills in individual inventors. There is a long line of research demonstrating that under standard conditions there are returns to worker specialization and firms maximize productivity when work and workers are as specialized as possible (Rosen, 1983). However, in dynamic environments, workers with general skills are more valuable because general human capital can be redeployed (Gervais et al., 2005). In entrepreneurial firms, where there is uncertainty about future conditions and few individuals perform a broad set of tasks, individual skill breadth is a valuable resource (Lazear, 2005).

In generating new opportunities, individuals must be able to apply their existing knowledge in new and innovative ways. We assume that the breadth or generality (Hall et al., 2001) of an inventor's patent portfolio captures inventors' experience in applying their knowledge to new classes and thus is a proxy for creative capacity. With increases in breadth of their patent experience, inventors demonstrate a stronger capability to create opportunities to pursue new patent classes. For example, creating new products requires a combination of novel elements (Schumpeter, 1934). The broader an inventor's patent portfolio, the more opportunities for novel combinations may be recognized.

H2: The *probability that an inventor will patent in a new patent class is positively related to the generality of their individual patent portfolio.*

3.3. Collaborative capacity

The third dimension of absorptive capacity that we propose will affect the firms' ability to reconstruct technological capabilities through reallocation of extant individual inventors is collaborative capacity. The capability to learn and problem solve, essential for absorptive capacity, is evidenced in teams. Multiple actors working together increase the value of the social network and the flow of knowledge between actors (Fleming and Juda, 2004). The presence of at least one team member with relevant experience would increase both the assimilative capacity and the creative capacity of the group.

The technology R&D context (especially within entrepreneurial firms) is a dynamic environment where inventors operate at the frontier of technology and where innovation relies on diverse actors focusing on a new technology strategy (Garud and Karnoe, 2003). Departing from a conceptualization that vests the agency in entrepreneurship with specific individuals suggests that technology R&D in entrepreneurial firms is a larger process that builds upon the efforts of many (Van de Ven, 1993; Mezias and Kuperman, 2001; Garud and Karnoe, 2001, 2003). Skills and resources required to take an idea from its inception to fruition have to be mobilized by drawing upon the creative capability of actors from multiple domains (Karnøe, 1996). In other words, entrepreneurial agency is distributed across actors (Garud and Kotha, 1994; Tsoukas, 1996).

The number of inventors on collaborations with relevant experience is a proxy for collaborative capacity or the ability to capitalize from direct between-individual knowledge spillover. As the number of inventors with relevant experience increases, there is a positive impact on any individual scientist to successfully exploit opportunities in a new patent class.

H3: *The probability that an inventor will patent in a new patent class is positively related to the number of co-inventors with prior experience in the new patent class.*

4. Inventor bricolage and external capabilities

Organizations typically utilize a variety of approaches to allocate human capital and can take on multiple methods simultaneously (Davis-Blake and Uzzi, 1993; Lepak and Snell, 1999). If the firm has resources and time, mergers and acquisitions are a method for firms to introduce external inventors and their capabilities into the firm (Walter and Barney, 1990). The benefits of any acquisition are unlikely to accrue through just the mere fact of joint ownership of assets, but rather the benefits depend on the extent to which the acquirer can integrate the targets resources with its own (Haspeslagh and Jemison, 1991). The effect of acquiring human capital through mergers and acquisitions on firms' bricolage strategies depends on the level of integration ranging from preservation of the acquired firm by the acquirer (low levels of organizational integration between the two firms) to absorption of the acquired firm by the acquirer (high levels of organizational integration between the two firms).

The integration of the smaller firm into the larger one may mean the destruction of the organizational properties of the smaller firm that contribute to making it a repository of innovation and technological capabilities. Thus, we argue that acquiring human capital through mergers and acquisitions has a substitutive effect on firms' bricolage strategies as the acquirer will integrate the acquired firm – i.e. 'absorb' technological abilities – and therefore not reconstruct new capabilities. If the firm were to 'preserve' the acquired firm, we would see complementary effects on firms' bricolage strategies as we would expect a new source of assimilative, creative, and collaborative capacity. Lastly, we would expect no effect if firms were to integrate in a symbiotic way – i.e. 'graft' new technological capabilities (Puranam et al., 2003). A lack of relationship would indicate that inventor bricolage is a stand-alone viable alternative to the traditional M&A buying option of building R&D capabilities.

We contend that new inventors brought into the firm do not necessarily facilitate knowledge spill-over to increase the likelihood of existing inventors successfully innovating in new areas. In fact, like Karim and Mitchell (2000), we argue that firms utilize M&A in a way that is resource deepening. M&A also requires reconfiguration of business resources (Karim and Mitchell, 2000). Reconfiguration involves the retention, deletion, and addition of resources (Capron et al., 1998).

Additionally, acquiring external knowledge reduces the need for firms to develop knowledge internally, so M&A activity will reduce future observed bricolage activities. Integrating external knowledge from acquisition can provide a means by which firms attempt to overcome the constraints on change that existing routines create (Capron and Mitchell, 1998; Singh and Zollo, 1998; Capron et al., 2001). In fact, M&A may degrade firm's internal technology R&D capabilities (Lei and Hitt, 1995). Also, more extensive acquisition activity may paradoxically result in the gradual externalization of many of the firm's value-adding activities over time. Therefore, we propose that recent M&A is negatively related to existing inventor bricolage as firms substitute external innovation for internal innovation, but as M&A events mature, knowledge spill-overs from the acquired scientists will diminish.

H4a: *Firms with high recent M&A activity will demonstrate less inventor bricolage than firms with low recent M&A activity.*

H4b: *Recent M&A activity will mediate the effect of internal capabilities.*

5. Method

5.1. Setting

We investigate inventor bricolage in the *In Vitro and In Vivo Diagnostic Substances* industry. The diagnostics industry is an ideal setting in which to study the use of inventor skills for innovation for theoretical as well as empirical reasons. Theoretically, we want to investigate how inventors are used in recombining and building innovative capabilities as opposed to external sourcing of innovative capabilities. As Hagedoorn and Duysters (2002) find in high technology industries where external sources of innovative capabilities of companies are related to core businesses, mergers and alliances are a preferred method of sourcing capabilities. In such a case, the role of integration becomes important as mergers and acquisitions provide more strategic control.

Empirically, like the rest of life sciences, the industry has a well-defined intellectual property (IP) landscape (Alcacer, Gittleman and Sampat, 2009). But unlike the rest of life sciences, the industry tends to have shorter R&D cycles as products are usually manifested in physical equipment within 2–3 years. Also in this industry, there are fluid and transparent labor markets with high barriers to entry. Experts move across companies, but it is hard to become an expert. Thus, M&A is a primary way in which expert skills are sourced as evidenced by the numerous M&A activities in the sector. In other words, there is a strong 'make vs. buy' decision because the IP does not move even if the people do. However, as described above, this empirical phenomenon of M&A might not lead to clear outcomes on the occurrence of inventor bricolage. Thus, the empirical setting is ideal for our investigation of conditions surrounding inventor bricolage activities.

5.2. Data

We test our hypotheses on patenting behavior of individuals using patent data from Delphion. The data allow extraction of 26 years of US Patent and Trademark Office (USPTO) patent data. We use patent data to capture utilization of inventors because of the direct relevance of patent data to the technology R&D context; the large sample sizes afforded in patent data; the information on inventor activity (Hall et al., 2001); and most important to this project, the assignment of patent classes, where patent classes indicate how a patent will be 'used' (Schmookler, 1966; Scherer, 1982). Moreover, we use granted patents as the criteria for truly new opportunities, as patents are granted based on criteria for novelty and usefulness. By analyzing the patent activity of individuals within firms, we can infer how inventors are entering new fields of use for their research.

We restrict our sample to all patents at publicly traded firms in the *In Vitro and In Vivo Diagnostic Substances* industry (SIC 2835) spanning 1992–2005. Firms in this industry are highly entrepreneurial as innovations are substances used for diagnostic tests performed in test tubes, petri dishes, machines, and other diagnostic test-type devices. In this young and dynamic industry, IP and patent protection are critical (Arora et al., 2001), so patent activity is a useful proxy for innovation and innovation strategy. We focus on publicly traded firms to ensure that firms have the same over-arching objectives and to ensure that firms are at similar places in the firm-life cycle.

Using the patent-level data from the USPTO, we construct both firm-level and inventor–patent-level databases. Every patent is associated with a list of one or more individual inventors; one or more sponsoring firms; a date of filing; and a patent class that captures the area of the patent. Using these data, we create a longitudinal database of inventors that tracks every patent in the industry for each inventor. Using the inventor–patent observations we can reconstruct the patent path of individuals and analyze the characteristics of individual inventors' patents across time. We then aggregate the individual-level data to the firm level to capture firm outcomes. Specifically, we aggregate all measures to the firm level to capture the average characteristics of the workforce.

For every firm in the sample, we link to financial data collected from SEC filings available on Compustat. To capture time-varying firm characteristics, we link each patent observation with firm financial data for the year in which the patent was filed. Descriptions of the key variables are available in Table 1.

5.3. Variable definitions

For all variables, we start with measuring individual-level constructs and then aggregate to construct firm-level measures.

5.3.1. Dependent variable: patenting in a new class

Our dependent variable, *New Class*, captures if inventors are patenting in a field of use that is new to the inventor. The variable is coded as a 1 if an inventor is awarded a patent in a patent class that differs from all prior patents they have been awarded, the variable is coded as a zero otherwise, where patent class is the first four digits of the IPC-R patent classification system. Of the 8,161 patent–inventor observations in the full dataset, 1,602 represent initial patents for the inventors. Because we focus on how inventors discover or create with respect to their prior patenting activity, we examine the dataset of 6,559 non-initial patents of which 663 observations are patents that represent activity in a new patent class for the inventors. We then calculate the average of the *New Class* variable for all inventor–patent dyads within each firm. This measure captures the extent to which firms engage in inventor bricolage by calculating the percent of events where inventors patent in a new class divided by the total number of inventor patenting events. Summary statistics of the key firm-level variables are available in Table 2, summary statistics of the individual-level data are available in Table 3.

Our data begin in 1992, so if the inventor has patented in the industry before 1992, we may undercount their prior patents. This may bias our results by creating false positive in the *New Class* variable. The bias should be greatest in early years of the sample. To mitigate this bias, we include a set of year dummies to absorb variation that is correlated across time.

Table 1. Operationalization of key variables appearing in the model

Dependent variables	
Inventor bricolage	= 1 if patent is in new patent class for inventor, = 0 otherwise
Explanatory variables	
Number of *Prior Patents*	= # of patents to date for the inventor in the current firm
Individual Patent Portfolio Generality	= generality measure of individual inventor's patent stream (see text for details)
Co-Inventor Count	= # of inventors on the patent
Co-Inventor Density	= percentage of other inventors on the patent that have previous patents in the patent class
M&A activity in prior 2 years	= 1 if firm experienced any M&A activity in prior 2 years, = 0 otherwise
Key controls	
Sales	Sales (in US$1,000s)
Cost of Goods Sold	Cost of Goods Sold (in US$1,000s)
Current Assets	Current Assets – Total (in US$1,000s)
Instrumental variable	
M&A activity 3 or more years prior	= 1 if firm experienced any M&A activity 3 or more years prior, = 0 otherwise

5.3.2. Key explanatory variables

The key explanatory variables in our study are prior patent activity, individual inventor generality, number of co-inventors, and percent of co-inventors with prior patenting activity in the target patent class.

To proxy for individual-level assimilative capacity, we measure the depth of inventors' patenting experience. Specifically, we construct a variable, *Prior Patents* (*PP*), which captures the number of patents that each inventor has to date while employed in the industry. This variable is a composite measure that captures both inventor productivity and inventor tenure in the industry. Ideally we would control for inventor tenure separately, but due to the lack of inventor demographic controls we are unable to parse tenure and patenting rate. This measure is susceptible to left censoring – we do not account for patenting activity before 1992. The distribution of *PP* is highly skewed. At the last observation for each inventor, the median number of prior patents is 3, the mean is 8.3. The mean is much larger than the median because several who are named on over 100 patents each. Excluding the superstars in our analysis has a negligible effect on the estimates so we choose to include them throughout the analysis. To convert to a firm-level measure, we calculate the average number of prior patents for each active inventor in the firm. This measure proxies for the assimilative capacity of the firm's workforce.

To capture individual-level creative capacity we create a measure of inventor breadth. We construct a measure of IPPG. For every inventor at every time period in our data we modify the generality measures of Hall et al. (2001) to measure the generality of the patent portfolio of an individual inventor. We construct a Herfindahl-type index that captures the distribution of the individual inventor's patents across patent classes. Specifically, we calculate the IPPG as follows:

$$G_{it} = 1 - \sum_{j=1}^{n_{it}} s_{ijt}^2$$

where i indexes the individual inventor, j indexes patent classes, and t indexes time, s_{ijt} is the share

Table 2. Firm level descriptive statistics and correlations

	Variables	*N*	Mean	SD	1	2	3	4	5	6	7	8	9
1	Patents in *New Class* for inventor	197	0.193	0.277	1.000								
2	*Prior Patents*	197	7.378	12.249	−0.162	1.000							
3	*Individual Patent Portfolio Generality*	197	0.414	0.321	0.697	−0.002	1.000						
4	*Co-Inventor Count*	197	3.480	1.587	0.043	0.301	0.063	1.000					
5	*Co-Inventor Density*	197	0.298	0.296	0.842	−0.213	0.567	0.137	1.000				
6	*M&A* activity in prior 2 years	197	0.180	0.371	0.285	−0.088	0.185	0.123	0.221	1.000			
7	*M&A* activity 3 or more years prior	197	0.203	0.400	0.108	0.186	0.106	0.212	0.065	0.311	1.000		
8	Sales	197	0.242	1.083	0.060	0.003	0.069	0.125	0.076	0.136	0.127	1.000	
9	*Cost of Goods Sold*	197	0.095	0.242	0.153	0.070	0.130	0.156	0.152	0.316	0.295	0.864	1.000
10	*Current Assets*	197	0.229	0.771	0.018	0.127	0.059	0.200	0.038	0.124	0.117	0.939	0.768

of inventor *i*'s patents in class *j* by time *t*, n_{it} is the number of classes in which inventor *i* has patented by time *t*. G_{it} can range from 0 to $\frac{n_{it}-1}{n_{it}}$. We normalize the measure of individual inventor patent generality by scaling by $\frac{n_{it}}{n_{it}-1}$to get:

$$IPPG_{it} = \lim_{n \to n_{it}} \frac{n}{n-1} G_{it}$$

where $IPPG_{it}$ varies from 0 to 1.

This measure captures the extent to which an individual inventor has recombined existing skills into new areas. In our data, of the 909 unique inventors who appear on multiple patents, approximately 53% do not undertake inventor bricolage (they patent in only one patent class and their patent portfolio generality measure is equal to zero at all time periods). The mean value for the remaining 47% of observations is 0.787 (for interpretation, an inventor that has two patents in class A, two in Class B, and one in Class C has a generality measure of 0.8). Again, we aggregate this measure to the firm-level and calculate the average patenting breadth of all active inventors in the firm.

To proxy for the direct knowledge spill-over inherent in team projects, we include a measure of the number of co-inventors listed on each patent, *Co-Inventor Count* (*CC*) as well as the percentage of co-inventors that have prior experience in the patent class, *Co-Inventor Density* (*CD*). The *CC* variable is a simple count of the number of inventors listed in the patent filings. For our analysis, it is not necessary to account for the relative contribution an inventor has to each patent. For this reason, we weight participation on a co-authored patent equivalently to participation on a sole-authored patent. Across all 1,854 unique patents in our sample, approximately 13% are sole authored and 80% have four or fewer authors. Three patents in the sample have 27 co-authors. The mean number of coauthors is 3.5 and the median is 3.

The *CD* measure captures the amount of potential direct knowledge spill-over in a given patent class. If an inventor is co-inventing with scientists who have direct prior experience in a technology, the inventor is potentially more likely to patent in that technology class, even if they have no prior experience in that class. The variable is constructed by patent–inventor pair as the percentage of co-inventors who have previously patented in the same patent class The *CD* measure has a mean of 14.4. 57.7% of the observations have *CD* equal to 0 (no co-inventors have relevant experience) and 16.14% of the observations *CD* equal to 1 (all co-inventors have relevant experience). Both of the co-inventor measures are also aggregated to the firm level.

Finally, to measure external knowledge acquisition, we include a measure of mergers and acquisitions activity, where M&A activities are commonly used in this industry to expand capabilities. We measure M&A activity by looking at the timing of when firms in our universe merged or acquired an outside firm. Because the distinction between recent M&A and mature M&A is important to our hypotheses, we focus on a 2-year window of M&A activity. Appendix Table A1 contains detail of the timing of M&A activity on inventor bricolage. Estimation of a simple logit model on the impact of M&A timing on inventor bricolage demonstrates that recent M&A activity has a different impact on the dependent variable than mature M&A activity, and the discontinuity occurs at the 2-year mark. This break at 2 years is consistent with the life cycle of patents in this industry. Any patents granted within 2 years of an

Table 3. Individual descriptive statistics and correlations

	Variables	*N*	Mean	SD	1	2	3	4	5	6	7	8	9
1	*New Class*	6,559	0.101	0.301	1.000								
2	*Prior Patents*	6,559	42.840	73.034	−0.157	1.000							
3	*Individual Patent Portfolio Generality*	6,559	0.410	0.343	0.355	0.089	1.000						
4	*Co-Inventor Count*	6,559	5.763	4.815	−0.003	0.043	−0.040	1.000					
5	*Co-Inventor Density*	6,559	0.144	0.283	0.765	−0.166	0.304	−0.028	1.000				
6	*M&A* activity in prior 2 years	6,559	0.218	0.413	0.057	−0.186	0.082	−0.151	0.082	1.000			
7	*M&A* activity 3 or more years prior	6,559	0.632	0.482	−0.117	0.383	0.032	0.343	−0.219	−0.113	1.000		
8	Sales	5,500	0.074	0.437	0.069	−0.079	0.015	−0.051	0.112	0.039	−0.086	1.000	
9	*Cost of Goods Sold*	5,500	0.166	0.120	−0.029	0.276	0.054	0.224	−0.087	−0.014	0.598	0.578	1.000
10	*Current Assets*	5,500	0.604	0.567	−0.091	0.057	0.053	0.140	−0.127	0.296	0.410	0.399	0.547

M&A event are likely to have originated before the M&A event, similarly patents granted 3 or more years after an M&A event likely originated after the M&A activity. These simple results suggest that recent M&A complements inventor bricolage, while mature M&A substitutes for inventor bricolage. In the rest of the analysis, we create measures of recent M&A activity (within 2 years) and mature M&A activity (activity that occurred 3 or more years prior) and use these two measures as concise controls for a firm's M&A history.

5.3.3. Key control variables

We include firm-level controls and year dummies in all specifications. Because firm size and firm cost structure may impact individual inventor behavior, we use financial data from Compustat to control for these time-varying firm characteristics. Our firm-level controls include *Current Assets*, *Sales*, and *Cost of Goods Sold*. We include *Current Assets* to control for firm size. In different specifications, we control for *Sales*, a flow-based measure of size and *Cost of Goods Sold*, which captures the product market in which the firm is operating. In our initial specifications, we included *Current Liabilities* to address firm debt issues, however, this measure was highly co-linear with the other firm-level controls.

5.4. Model specification and estimation

We examine our hypotheses on the impact of prior inventor breadth, depth, and knowledge density on the innovation outcomes of individuals. We focus on whether inventors are patenting in a patent class that is new to them or in a patent class in which they have previously patented. Because this measure of inventor utilization is a dichotomous variable, we test our hypotheses using a standard panel logit framework.

Specifically, to test our hypotheses at the firm-level, we estimate a panel regression of the rate of inventor bricolage as a function of firm and workforce characteristics:

$$NewClass_{ft} = \alpha_1 PP_{ft} + \alpha_2 IPPG_{ft} + \alpha_3 CC_{ft} + \alpha_4 CD_{ft} + \alpha_5 MA_{ft} + X_{ft}\beta_{ft}$$

where f indexes firm, t indexes time, and the explanatory variables and control variables are as described above. We also include firm fixed effects to capture time-invariant unobserved firm characteristics. For the test of Hypothesis 1, we examine the coefficient on *PP* for Hypothesis 2, we examine *Individual Patent Portfolio Generality*, for Hypotheses 3 we examine the *CC* and *CD* measures, and for Hypothesis 4 we examine the *M&A* (MA) variable and interactions.

6. Results

Table 4 contains our results on inventor bricolage at the firm level. The model estimates the relationship of a firm's workforce characteristics on the reallocation of inventors. The primary findings indicate that breadth of the inventive workforce and the relevant experience of co-inventors is positively related to firms' rates of inventor reallocation.

We find that the IPPG measure of the firm is positively related to the reallocation of inventors within the firm. The finding implies that the breadth of a individuals in the firm's workforce is positively related to inventor bricolage which supports Hypothesis 2. In other words, firms with workers with diversified patenting histories are more likely to demonstrate reallocation of inventors. This captures the creative capacity of the firm and indicates path dependence in firm's patenting patterns. Workers in firms with narrowly specialized inventors tend to stay narrowly specialized, workers in firms with broad inventors tend to develop a broad patent portfolio.

In support of Hypothesis 3, we find that *CD* has a positive and significant effect on inventor bricolage. *CD* measures the extent to which inventors patent with colleagues who have experience in the technological domain. Our finding suggests that inventors who work with inventors who have experience in a particular domain are more likely to patent in that particular domain. This implies that knowledge spillover between scientists is a positive predictor of inventor bricolage.

Table 4. Estimates of probability of a firm engaging in inventor bricolage

Mean *Prior Patents* per inventor	0.001
Mean *Individual Patent Portfolio Generality*	0.321***
Mean *Co-Inventor Count*	−0.015
Mean *Co-Inventor Density*	0.569***
M&A activity in prior 2 years?	−0.058
Prior patents × recent *M&A* activity	−0.008
IPPG × recent *M&A* activity	0.088
Co-Inventor Count × recent *M&A* activity	0.011
Co-Inventor Density × recent *M&A* activity	0.193
Constant	−0.182***
Firm controls?	Y
Year effects?	Y
N	197

Model is a panel logit specification with firm fixed effects.
***Significance at the 1% level.

We do not find support for Hypothesis 1. The estimated relationship between the average number of prior patents at the firm and inventor reallocation is not significant. We also find that recent M&A activity is unrelated to inventor bricolage. Additionally, we find no significant impact of the interaction of M&A activity and the previous predictors of inventor bricolage. In other words, recent M&A does not appear to directly impact internal human capital strategies, nor does it mediate existing internal bricolage capabilities which does not support Hypotheses 4a and 4b. Similarly, there does not appear to be any complementarities between M&A-driven external capabilities and internal capabilities. In summary, we find support for Hypotheses 2 and 3, and we do not find support for Hypotheses 1, 4a, and 4b.

6.1. Robustness results

To check the robustness of our empirical results, we retest our hypotheses at the individual level. While inventor bricolage is a firm-level construct, there may be dynamics at the individual level that are lost upon aggregation to the firm level. As a robustness check, we examine how individual inventors are utilized within firms. Specifically we estimate a panel logit specification at the individual-level of the following model (including firm fixed effects):

$$\Pr(NewClass_{ift} = 1) = \Phi(\alpha_1 PP_{it} + \alpha_2 IPPG_{it} + \alpha_3 CC_{it} + \alpha_4 CD_{it} + \alpha_5 MA_{ft} + X_{ft}\beta_{ft})$$

where Φ is the standard cumulative normal distribution, i indexes the individual inventor, f indexes firm, t indexes time, and the explanatory variables and control variables are as described above. If unobserved inventor characteristics are driving the innovation outcomes, then the reported estimates might represent only spurious correlation. However, because we have multiple observations across individuals, we can include individual fixed effects, which allow us to control for time-invariant unobserved individual characteristics. Again, to test Hypothesis 1, we examine the coefficient on *PP* for Hypothesis 2, we examine IPPG for Hypotheses 3 we examine the *CC* and

CD measures, and for Hypothesis 4 we examine the *M&A* (MA) variable and interactions.

Table 5 provides the baseline results of the analysis of the hypotheses regarding the firm conditions that are related to successful inventor bricolage. The models both include inventor fixed-effects, firm controls, and year controls. Model (a) does not include firm random effects, model (b) does include firm random effects. We estimate both specifications to examine whether unobserved, time-invariant firm characteristics impact the likelihood of inventors to engage in bricolage. We use random effects instead of fixed effects because we are not interested in estimating the firm effect directly and we do not want to exhaust degrees of freedom including fixed effects. The estimates in the table are for the logit coefficients of the variables on the probability of an inventor's patent being in a patent class that is new to the inventor.

In both specifications we find support for Hypothesis 1: the estimated marginal effect of the *PP* variable on the probability to patent in a new class is negative and significant. Under the assumption that the number of prior patents proxies for an individual's assimilative capacity, this implies that individuals' assimilative capacity is negatively related to inventors' likelihood to patent in a new patent class.

Table 5. Estimates of probability of inventor patenting in a new class

Variables	a	b
Prior Patents	−0.011*	−0.024***
Individual Patent Portfolio Generality	4.328***	2.944***
Co-Inventor Count	−0.005	0.051**
Co-Inventor Density	12.713***	9.721***
M&A activity in prior 2 years	−0.166	−1.45
Prior Patents × recent *M&A* activity	0.009	−0.015
IPPG × recent *M&A* activity	1.509	1.326
Co-Inventor Count × recent *M&A* activity	0.122	0.035
Co-Inventor Density × recent *M&A* activity	−1.881	0.37
Firm controls?	Y	Y
Year effects?	Y	Y
Inventor fixed effects?	Y	Y
Firm random effects?	N	Y
N	4,451	5,297

All models are panel logit specifications with inventor fixed effects.
*Significance at the 10% level,
**Significance at the 5% level,
***Significance at the 1% level.

The estimated marginal effect on patenting in a new class of the IPPG measure is positive and highly significant in both models implying that inventors with a patent history that is not specialized are more likely to patent in a new class which supports Hypotheses 2. In other words, inventors with breadth of experience, which proxies for creative capacity, are more likely to demonstrate new patent class innovation.

CC has a positive and significant effect on inventor bricolage when controlling for firm random effects, but is not significant when firm random effects are excluded. The marginal effect of *CD* is positive and significant in both specifications. These findings support Hypothesis 3 and imply that after controlling for unobserved firm characteristics knowledge spillovers between scientists are a positive predictor of inventor bricolage.

Again, we find no significant impact of the interaction of M&A activity and the previous predictors of inventor bricolage, which does not support Hypotheses 4a and 4b. Our results are robust to different levels of analysis. At both levels we find that an inventor's creative capacity and their exposure to co-inventors with relevant experience are positive predictors of an inventor being utilized in a new patent class. We also find a consistent lack of support for the hypothesis that the addition of external capabilities through M&A influences the patenting activities of a firm's inventors.

7. Discussion and conclusions

This paper links firm's patenting patterns to characteristics of the firm's workforce and then examines the dynamics of individual inventor's patenting portfolio within firms. Our findings suggest that regardless of M&A activity, R&D managers should assign inventors with more creative capacity (i.e., more broad past patenting experiences) in teams where there are co-inventors with relevant experience in order to reallocate human capital in R&D opportunities.

Our study contributes to the literature in several dimensions. First, we contribute to the literature on bricolage by exploring the ability of firms to reallocate human capital in the face of resource constraints. At the core, bricolage is about adapting existing resources to new challenges. As the needs for resources change, firms can adapt by building the new necessary resources, by buying the new resources, or by creatively utilizing their existing resource in a way that satisfies the demands of the new business environment. These three approaches apply to how firms can adapt to changing needs of physical resources, but also to changing needs in human capital.

If firms need to adapt their pool of human capital due to changing business conditions, they can hire workers with new skills, they can provide training to their existing workforce, or they can determine how to reallocate the existing pool of human capital to address the changing conditions. In this study, we examine the reallocation of existing inventors to the pursuit of new technological fields. We provide evidence that firms adapt their workforce to changing conditions through the process of using their existing workers in novel ways and not through the acquisition of external resources. This is an important step in understanding the role of bricolage, especially in the context of human capital bricolage.

Second, we add to the conceptualization of and understanding of assimilative and creative capacity. Although there is a long line of research on absorptive capacity, there is a big gap in the literature in understanding the role of individuals in developing and exploiting absorptive capacity. We also differentiate assimilative capacity and creative capacity. These constructs capture very different phenomena and should be treated as separate constructs. Second, the results of this paper begin to capture the evolution of inventor's patenting behavior as it occurs within an entrepreneurial firm. In the extensive patent-based research, little attention is paid to individual-level outcomes and dynamics. We find that it is extremely important to understand the patenting process at the level of the individual. It is important to understand the evolution of individual inventors in order to understand the organizational growth of the firm.

A third contribution is that we develop a novel approach to characterizing inventor attributes and the dynamics of firms' and inventors' patent portfolios. Patent portfolios evolve to adapt to changing business conditions. The internal resources of the firm and the characteristics of the workforce influence how patent portfolios evolve. If firms have a workforce where inventors specialize and all inventors specialize in the same technological discipline, then it is very unlikely for the firm to adapt to changing human capital needs by reallocation of their existing resources. Firms that are most likely to engage in inventor bricolage are firms that have inventors with a broad portfolio and have a workforce that covers a broad range of patent classes. This logic, however, raises some causality concerns. Do firms engage in inventor bricolage because they have inventors with broad patent portfolios, or do firms have inventors with broad patent portfolios because they have engaged in reallocation of the inventive workforce? Although we currently do not address this causality issue, we do demonstrate that these factors are related which adds to the understanding of how firms' and individuals' build patent portfolios over time.

Finally, by examining the relationship of bricolage and M&A on human capital utilization, we test the impact of simultaneously using multiple approaches to adjust firms' human capital. While the current literature demonstrates that there is value in the use of a variety of approaches (Davis-Blake and Uzzi, 1993; Lepak and Snell, 1999) for developing capabilities, in this context, external acquisition of capabilities through M&A was not a significant factor, but our evidence suggests that internal development and allocation of talent is important. While we focus only on one industry, our approach is generalizable to other industries. Analysis of the evolution of inventor patent portfolios can provide insights into how any unit of organization that generates patents responds to changing market conditions. Specifically, this method can be applied to the firm level and to the industry level, which would provide a useful framework to think about the nature of innovation and the type of entrepreneurship across observations.

Our study has several limitations. First, is the causality issue mentioned above. However, a longer time series of patenting behavior would allow a more detailed examination of the intertemporal dynamics and would facilitate teasing out the causality in the underlying relationships. A second issue is that data limitations prevent us from separating true bricolage events where inventors are made to adapt their knowledge to a new technological field and instances where inventors have received external training in the new field.

Another data limitation is that studies of patenting behavior face a number of selection issues. In our context, we only observe outcomes for research activities that successfully result in the generation of patentable knowledge and that result in knowledge that the employing firm chooses to patent (as opposed to protecting with other IP tools). If these selection characteristics are correlated with inventor breadth and research team breadth, than our results are biased.

Several avenues of future research would provide fruitful to the further understanding of resource reallocation in high-technology, entrepreneurial firms. First, a cross-industry study would provide valuable insights into how industries differ in how they respond to demand shocks. Second, while this study looks at the conditions of occurrence of inventor bricolage, it would be useful to look at the firm level performance impact of those firms that employ inventor bricolage. We believe that inventor bricolage is crucial for small firms to reduce dependence on external sources of capabilities. Also, in line with Karim and Mitchell (2000), it would be fruitful to look at the change in inventor bricolage of the merging firm to look at the combined effect of M&A over internal growth across firms.

Our findings suggest that managers should tailor their hiring practices and how they organize teams to match the volatility of their market. If a firm operates in an industry or sector where change is prevalent and human capital needs change frequently, the firm should adapt hiring and team allocation strategies that maximize the ability to engage in human capital bricolage. Specifically, managers should hire inventors with broad backgrounds or who otherwise demonstrate high creative capacity, they should then organize teams around exposing inventors to other inventors with different skill sets. This approach facilitates knowledge spillover and creates a workforce that can quickly adapt to changes in the marketplace.

However, there are tradeoffs associated with hiring a broad workforce and assigning workers to broad teams. If there are gains to specialization, then there is value to hiring specialized worker and organizing specialized teams that is foregone in order to build a broad workforce. Managers need to recognize the volatility of their business environment and determine if industry volatility is sufficiently high that the gains associated with building a highly adaptable research staff outweigh the costs associated with foregone returns to specialization. At the extremes, the managerial decision is straightforward: in a static industry, focus on specialization of both individuals and of research teams, in an extremely dynamic industry, focus on generalization of individuals and teams.

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Appendix A

Table A1. Estimates of M&A timing on patenting in a new class

	a
M&A activity 0–3 months prior	−0.306
M&A activity 3–6 months prior	0.426*
M&A activity 6–12 months prior	0.239
M&A activity 12–24 months prior	0.311**
M&A activity 24–36 months prior	−0.169
M&A activity 36–48 months prior	−0.590***
M&A activity 48–60 months prior	−0.755***
M&A activity 60+ months prior	−0.153
N	6,559
R^2	0.03

Model is a logit specification.
*Significance at the 10% level,
**Significance at the 5% level,
***Significance at the 1% level.