Structural Recombination and Innovation:

The Roles of Technological Capability and Coherence

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Structural Recombination and Innovation

ABSTRACT

This paper examines how structural recombination of business units impacts subsequent firm innovation. We argue that structural recombination has a disruptive effect on the firm’s routines and capabilities, causing innovation to decline following the merging together of business units. The magnitude of this effect depends upon the strength and coherence of firm knowledge, however, with the disruption being most harmful for firms with weak and diffuse technological capabilities. In contrast, firms with strong and coherent technological capabilities may realize gains from recombination of knowledge as a result of the change in intra-firm boundaries, so that structural recombination may have a positive effect on innovation in such firms. Results from a 20-year panel of 71 firms operating in the U.S. medical sector confirm these arguments. The study thus provides a contingent view of the effects of structural recombination on firm innovation, while also highlighting the potential for structural change to be a means of unlocking the potential for knowledge recombination within the firm.

Key words: recombination, innovation, reconfiguration, structure, knowledge, technological capability, technological coherence
Structural Recombination and Innovation

INTRODUCTION

Structural recombination, or the change in organizational structure resulting from the merging together of business units, is an important and widespread business phenomenon. Prior work in the strategy literature has examined the consequences of such organizational restructuring, often finding a negative effect on firm performance resulting from the unanticipated disruptive effects of such changes (Bowman et al., 1999; McKinley and Scherer, 2000). These disruptive effects have prompted scholars to caution firms to use structural change sparingly as a tool for performance improvement (Miller, 1982; Nadler and Tushman, 1997). The focus of this work has been on the effect of these reconfigurations on firm financial performance, however, leaving the question of how structural recombination impacts firm innovation largely unexplored (see Karim, 2009 for a notable exception). Examining the effect of structural change on innovation is important because a substantial body of recent work in the technology literature has highlighted the recombinant nature of innovation (Kogut and Zander, 1992; Weitzman, 1998; Fleming, 2001; Nerkar, 2003), suggesting the need to study how organizational restructuring may impact the potential for knowledge recombination within the firm.

In this study, we attempt to bridge this gap in the literature by examining the effect of structural recombination on firm innovation. Building off recent work (Karim, 2009), we argue that structural recombination will have a disruptive effect on firm innovation, causing innovation performance to decline following structural change. Moving beyond this average effect, however, we propose a contingent theory of the effect of structural recombination on innovation,
with the extent of the decline depending upon the strength and coherence of the firm’s technological knowledge. Where firm technological capabilities are weak and widely diffused, we argue, the disruptive effects of structural recombination will be strongest, and innovation will decline substantially. In contrast, firms with strong and coherent technologies will be able to overcome the disruption caused by structural change more easily and may, in fact, benefit from the change as the merger of business units unlocks the potential for knowledge recombination within the firm.

These arguments are tested on a sample of 71 firms from the U.S. medical sector, using panel data from 1978-1997 that combine a detailed record of the evolution of their business units with information on firm patenting. Our results show that while structural recombination has, on average, an insignificant effect on subsequent firm innovation, the impact of structural recombination is strongly contingent on the firm’s existing knowledge resources. In particular, structural recombination has a positive effect on innovation when firms have strong technological capabilities or when their knowledge base is technologically coherent, but a negative effect when firms are technologically diversified in incoherent ways.

These findings contribute to the literature on organizational change in general, and organizational restructuring in particular, by shedding new light on the effect of structural change on firm innovation. In particular, our work goes beyond the main disruptive effect of structural change, to present a contingent perspective, with the outcome of structural recombination depending upon the strength and coherence of firm knowledge. Moreover, by providing evidence for a positive effect of structural recombination on innovation in firms with a strong and coherent knowledge base, the study emphasizes the opportunity for firms to unlock the potential for internal knowledge recombination through the redrawing of intra-firm boundaries. As such, our
study also contributes to the literature on technology and innovation, especially to work that deals with internal boundary-spanning (Rosenkopf and Nerkar, 2001) as a means of knowledge recombination within the firm (Hargadon and Sutton, 1997; Galunic and Rodan, 1998; Katila and Ahuja, 2002). While the focus of this work has generally been on the transfer of knowledge between divisions (Argote and Ingram, 2000; Miller, Fern and Cardinal, 2007; Tortoriello, Reagans and McEvily, 2011), our findings suggest that an alternate way that firms can realize intra-firm knowledge recombination is by redrawing the internal boundaries of the firm.

The paper is organized as follows. It begins with background on relevant literature and draws on this literature to develop hypotheses. This is followed by methods and measures which outline the data and sample, operationalization of variables, and the methodology of this study. Finally, the paper concludes with a description of our results and a discussion of their implications.

BACKGROUND & HYPOTHESES

Structural Recombination

Structural recombination refers to changes in business units as their resources and market activities are reorganized by merging units together, generally through the absorption of one unit into another unit or the formation of a new business unit by combining existing units. Units may have different origins, being either internally developed, acquired or the result of a former recombination. Figure 1 provides several examples of structural recombination.

*** Figure 1 about here ***

While there is relatively little work directly examining the effect of structural change on firm innovation, the phenomena of internal boundary changes broadly referred to as ‘reorganizations’ have been examined at various units of analysis in studies on organization design, acquisitions,
diversification and dynamic capabilities. Of these, the work that comes closest to the current study is work in the dynamic capabilities literature, which studies the ‘patching’ and ‘reconfiguration’ of market activities by changing divisional boundaries, resulting in the movement of the underlying resources within the firm (Brown and Eisenhardt 1997; Eisenhardt and Brown 1999; Karim and Mitchell, 2004). Patching involves “…adding, deleting, splitting, transferring or combining chunks of businesses” as firms frequently remap their structures to react to changing market opportunities (Eisenhardt and Brown 1999: 73). Expanding upon this concept, Karim and Mitchell (2004) defined reconfiguration as the act of patching to realign with market conditions as well as purposeful experimentation and search for new opportunities. Firms usually attempt to create value through structural recombination before divesting a unit (Karim 2006), though the effect of such reconfiguration on new product line entry (via internal development, not acquisition) shows a U-shaped relationship (Karim, 2009).

It is worth noting that structural recombination as used here is different from, though related to, several other terms that are prevalent in strategy literature, including the redeployment of resources following acquisitions (Capron, Dussauge, and Mitchell 1998; Capron and Mitchell 1998), corporate restructuring through entry into new businesses and exit from existing ones (Porter 1987; Bowman and Singh 1989; Hoskisson and Johnson 1992), and studies of ‘charter changes’ that involve moving responsibility for a market activity from one division to another (Galunic and Eisenhardt 1996, 2001; Berkinshaw and Lingblad 2005). Indeed, a key reason we use the term ‘structural recombination’ is to distinguish our phenomenon of interest from these other kinds of organizational change that also involve structure.
Structural Recombination as a Disruptive Process

Changes in organizational structure are an important means of organizational adaptation, with firms ‘patching’ or ‘reconfiguring’ their market activities by changing divisional boundaries to react to changing external and internal opportunities (Brown and Eisenhardt, 1997; Eisenhardt and Brown, 1999, Karim and Mitchell, 2004). By merging together two or more business units firms can both recombine their internal resources (Galunic and Rodan, 1998; Verona, 1999) and realign them with market conditions (Eisenhardt and Brown, 1999; Karim and Mitchell, 2004).

These kind of structural changes are not without their challenges, however. As several studies have suggested, structural changes are disruptive events, with unintended consequences that may negate the potential benefits from the restructuring (Bowman et al., 1999; McKinley and Scherer, 2000). Because structure is one of the core elements of an organization (Hannan and Freeman, 1984; Hannan, Burton, and Baron 1996), with a complementary relationship to other key elements such as strategy, culture, work, power and people (Miller and Friesen 1984; Tushman and Romanelli 1985; Miller 1986; Miller 1996; Romanelli and Tushman 1994, Burton, Lauridsen, and Obel 2002), structural changes are likely to be disruptive or costly to firm performance (Miller, 1982). Changes in organizational structure will tend to disrupt the communities of practice within the organization (Brown and Duguid, 1991), which, in turn will compromise the collaboration between employees, negatively affecting their work, learning and innovation (Brown and Duguid, 1991; Orr, 1996). Structural recombination may also result in increased conflict within the organization. As units are recombined there may be conflict around where to place the resources of the absorbed unit; this management of resources may be costly, and may prove taxing to executives who need to make resource allocation decisions (Galunic and Eisenhardt 1996, 2001; Helfat and Eisenhardt 2004). Structural change may also be associated
with greater complexity, uncertainty and ambiguity within the organization (Luscher and Lewis, 2008). As a result, firms may face ‘post-restructuring drift’ (Johnson, Hoskisson and Margulies, 1990) as managers attempt to work through the paradoxes and conflicting organizational goals arising from the change (Cyert and March, 1963; Child, 1972; Luscher and Lewis, 2008) as well as the disconnect between formal and informal structure (Miller, 1992; Gulati and Puranam, 2009). Studies of post-merger performance have long recognized the disruptive effects of merging two organizations (Jemison and Sitkin, 1986; Buono and Bowditch, 1989; Greenwood, Hinings and Brown, 1996), and many of the coordination and communication difficulties discussed in this literature are likely to plague the merger of business units as well. Indeed, it is precisely such disruptions that have prompted scholars to caution firms to use structural change sparingly as a tool for performance improvement (Miller, 1982; Nadler and Tushman, 1997).

More specifically, for our purpose, changes in structure are likely to be especially disruptive to the firm’s knowledge processes and capabilities. As several authors have pointed out, organizational knowledge is often tacit (Nelson and Winter, 1982; Kogut and Zander, 1992), situated within context (Glynn, Lant and Milliken, 1994; Fisher and White, 2000) and embedded in routines (Cyert and March 1963; Nelson and Winter 1982; Levitt and March 1988). Since these routines and processes are embedded within the organizational structure, the act of changing boundaries and moving personnel may destroy some of these competencies. Structural recombination may also be accompanied by the departure of employees who are unhappy with the change (Dent and Goldberg 1999) and this may further deplete the tacit knowledge of the firm (Nixon et al., 2004; Guthrie and Datta, 2008), with the departure of employees resulting in the disruption of informal relationships (Dougherty and Bowman, 1995) and the loss of social capital (Dess and Shaw, 2001). This in turn may have a disproportionate effect on firm learning
(Fisher and White, 2000) and create a negative environment that inhibits creativity (Amabile and Conti, 1999).

These disruptions to the firm’s knowledge base may negatively affect the firm’s ongoing innovation efforts, so that the effect of structural recombination on firm innovation may be negative. There is some empirical evidence to suggest this. Karim (2009) examines structural reconfiguration and entry into new markets and finds support for a U-shape learning effect, though few firms achieve the positive upswing. She attributes this to the disruptive nature of reconfigurations, and argues that like most other processes, successful structural recombination is a learned process, one that the vast majority of firms do not gain enough experience with to benefit from (Karim 2009). Overall, then, structural recombination may be harmful to firm innovation, with prior work showing a negative effect of structural changes on innovation, on account of the disruptive nature of reconfiguration. We therefore hypothesize that:

*Hypothesis 1: Structural recombination will have a negative effect on firm innovation.*

**Structural recombination and knowledge recombination**

While the discussion above predicts a negative effect of structural recombination on innovation, there is also reason to believe that structural recombination has the potential to help improve firm innovation performance. A substantial body of work in the innovation literature has emphasized the role of knowledge recombination as a driver of innovation (Ahuja, 2000; Fleming, 2001; Katila and Ahuja, 2002; Nerkar, 2003). In particular, organization scholars have highlighted the role of knowledge recombination within the firm (Hargadon and Sutton, 1997; Galunic and Rodan, 1998), through the spanning of intra-organizational boundaries (Rosenkopf and Nerkar, 2001). While the focus of much of this work has been on the transfer or sharing of
knowledge across different parts of the organization within a given structure (Verona, 1999; Argote and Ingram, 2000; Jansen, Van den Bosch, and Volberda, 2005; Miller et al., 2007; Tortoriello et al., 2011), the potential for such internal knowledge recombination, coupled with the insights from the organizational reconfiguration literature (Brown and Eisenhardt, 1997; Karim and Mitchell, 2004) suggests that one way for firms to recombine internal knowledge may be by redrawing their internal boundaries. Structural recombination may thus be adaptive as well as disruptive (Amburgey, Kelly and Barnett, 1993) with the interruption of established routines and communities prompting wider search (Zellmer-Bruhn, 2003) and creating opportunities for intra-firm knowledge recombination (Rosenkopf and Nerkar, 2001; Katila, 2002).

The strength of this knowledge recombination effect is likely to differ from firm to firm. Scholars studying firm innovation have long recognized the heterogeneity of a firm’s ability to undertake knowledge recombination, referring to this ability as the firm’s combinative capability (Kogut and Zander, 1992), second-order competence (Rosenkopf and Nerkar, 2001) or architectural competence (Henderson and Cockburn, 2004). It follows that the effect of structural recombination on subsequent firm innovation may also vary from firm to firm. In particular, we argue that both the extent of disruption caused by the structural change, and the potential for knowledge recombination following it, will depend upon the nature of the firm’s technological knowledge base preceding the recombination. We therefore turn to consider the conditions under which the effect of structural recombination on innovation may be less harmful or beneficial.

**Technological Capability**

An initial factor that is likely to moderate the effect of structural recombination on innovation is the strength of the firm’s technology capability, or the quality of its knowledge. The inherent
potential of a firm’s technology is a critical part of its overall combinative capability (Kogut and Zander, 1992), with the strength or quality of the existing knowledge having a positive effect on the likelihood of valuable recombination (Nelson, 1982; Weitzman, 1998). Thus, firms with strong technological capabilities are in a better position to leverage recombination across diverse elements to generate valuable new innovations (Katila and Ahuja, 2002).

There are several reasons why firms with strong technological capabilities may be better positioned to reap the benefits of structural recombination for innovation. First, as already mentioned, strong technology capabilities will raise the potential value of recombinant innovation, since recombinant knowledge that draws on strong existing capabilities is likely to be more valuable (Nelson, 1982; Kogut and Zander, 1992; Weitzman, 1998).

Second, firms with strong technological capabilities may have a better understanding of the technologies they are looking to combine, which in turn may raise the potential gains from recombination. Scholars of innovation have emphasized the importance of cognitive search in the innovation process (Gavetti and Levinthal, 2000), with firms that have a strong understanding of the search space being able to achieve better outcomes in a more efficient manner. At the same time, a major reason why attempts at organizational change are seen to fail is the proclivity of firms to adapt for the sake of doing something different (Fiol and Lyles, 1985; Cardinal and Opler, 1995), with the lack of a clear direction in experimenting resulting in innovations that are less useful on average (Fleming, 2001). To the extent that firms with strong technological capabilities have a better understanding of the technologies they are looking to recombine, and a clearer insight into potentially valuable recombinations that could arise from these technologies, they are likely to realize greater benefits from structural recombination.
Third, units within firms that have strong technology capabilities may also have superior absorptive capacity (Cohen and Levinthal, 1990), and may be better able to absorb or engage with technological knowledge from other business units to enable successful recombination. Indeed, absorptive capacity is seen as being closely linked to firm combinative capabilities (Van den Bosch et al., 1999).

Finally, the factors above will not only enhance the potential value of knowledge recombination resulting from structural recombination, they may also reduce the disruption associated with the structural change. A cognitively informed and guided search process is likely to be less disruptive for the organization, and stronger intra-firm absorptive capacity may also make the transition to the new organizational structure easier. In contrast, where technological capabilities are weak, levels of stress within the organization may already be high before the structural recombination, so that the disruption associated with it is likely to be worse.

Overall, then, we expect firms with strong technological capabilities to have greater potential for valuable recombination, a superior ability to recombine their existing knowledge to generate valuable innovations, and relatively limited disruption during the process of structural recombination compared to firms with low technological capabilities. In addition, we expect these firms to be smarter in how they structurally recombine business units, using their superior technological understanding to identify the knowledge resources that they believe need to be brought together. For all these reasons, we hypothesize:

*Hypothesis 2: The negative relationship between structural recombination and innovation will be dampened by the strength of the firm’s technological capabilities.*
Technological Coherence

A second factor that may impact the effect of structural recombination on innovation is the coherence of a firm’s technological portfolio. The potential for knowledge recombination within the firm depends not only upon the strength of the firm’s technological knowledge, but also the breadth or diversity of its knowledge. On the one hand, greater diversity of knowledge implies a wider search space (Katila and Ahuja, 2002) with stronger absorptive capacity (Cohen and Levinthal, 1990; Nicholls-Nixon and Woo, 2003) and greater potential for knowledge recombination (Ahuja and Lampert, 2001). On the other hand, greater diversity of knowledge may increase complexity (Wang and von Tunzellman, 2000), making experimentation unwieldy as firm resources are stretched too thin (Hitt et al., 1996) and learning more difficult as firms move into unfamiliar areas (Helfat, 1994). In line with these arguments, prior studies have found a curvilinear relationship between technology diversity and innovation, with breadth of knowledge having an initially positive effect on innovation, but innovation declining as knowledge becomes too diverse (Ahuja and Lampert, 2001; Katila and Ahuja, 2002).

In this study, we argue that it is not so much the breadth of the firm’s technological knowledge that matters as the extent to which the various technological areas of the firm are related or unrelated to each other. In other words, it is not the firm’s technological diversity per se, but the coherence of its technological portfolio (Teece et al., 1994; Nesta and Saviotti, 2005). This idea of coherence was first articulated by Teece et al (1994), who argued and showed that firms are expected to be ‘coherent diversifiers’, maximizing the value from potential synergies by entering into lines of business that are related, in that they share common technological or market characteristics. Studies have shown that firms tend to diversify their technologies in coherent ways, “filling all the possible ‘technological gaps’ between [patent] classes” (Breschi et
al., 2003, p.86), and that such coherence has a positive effect on firm innovation performance (Nesta and Saviotti, 2005). In addition, technological complementarity or coherence between two firms has been shown to be critical to enabling recombination between the technology portfolios of merging firms (Cassiman et al., 2005; Makri et al., 2010).

There are several reasons why technological coherence may positively moderate the effect of structural recombination on subsequent innovation. First, high technological coherence will mean that the various technological areas the firm operates in are closely related, so that the potential for useful knowledge recombination will be greater given complementarities between units (Teece et al., 1994; Cassiman et al., 2005; Makri et al., 2010). Second, the ability of recombined units to work together to develop joint innovation will be greater because of the lower coordination and communication costs between different units within the firm (Tushman, 1978; Teece et al., 1994; Breschi et al., 2003; Nesta and Saviotti, 2005). As several studies have pointed out, intra-firm knowledge sharing is critically dependent on the existence of shared language (Dougherty, 1992), frames (Fiol, 1994), coding schemes (Zander and Kogut, 1995) and mental models (Galunic and Rodan, 1998) within the firm, and greater technological coherence implies the existence of these common elements linking the knowledge of different units. Third, greater technological coherence may also ameliorate the disruptive effects of structural change, both because individuals in related or complementary knowledge spaces may already have informal ties from being members of a shared community of practice (Brown and Duguid, 1991), and because the formation of new ties may be easier given shared language and understanding.

Given these arguments, we expect that coherent technological diversity may benefit the firm in its innovative efforts. Specifically, we propose that technological diversity in related areas will
diminish the negative impact of structural recombination on innovation, while unrelated technological diversity will exacerbate this effect. Thus,

_Hypothesis 3: The negative relationship between structural recombination and innovation will be dampened by the coherence of the firm’s technological portfolio._

**METHODS & MEASURES**

**Data and Sample**

The empirical setting for this study is the medical sector, including its three main industries of medical devices, pharmaceuticals, and healthcare service. Data was gathered from several editions of the "Medical & Healthcare Marketplace Guide", namely those published in 1978, 1983, 1986, 1989, 1993 and 1997.¹ The guides include information of firms operating in the U.S., and include both domestic and international firms. Information is available on each firm and its business units, along with the reconfiguration history of how units were recombined over time. There is also information at the firm level about performance and degree of diversification (outside of the medical sector).

This detailed information on firm organization and reconfiguration is augmented with data on firm technology, specifically data on the patents filed by firms with the USPTO. Patent data has been widely used in the technology literature to measure firm knowledge and innovation (Ahuja and Lampert, 2001; Fleming, 2001; Rosenkopf and Nerkar, 2001; Nerkar, 2003; Miller, Fern and Cardinal, 2007), and the richness of information available with this data allows us to construct meaningful measures of each of our main constructs – technology quality and coherence, as well as a measure of firm innovation overall. Note that the use of patent data also allows us to study

innovation at a more granular level than prior work that has examined the effect of reconfiguration on firms’ entry into new product markets (Karim, 2009). Patent data for the firms in our sample is obtained by matching each firm to a few individual patents by searching for the firm’s name in the USPTO database, and then searching the NBER patent database (Hall et al., 2001) to identify all other patents belonging to the focal firm. Patent data are available for all patents granted up to 2006, allowing us to study firm innovation for a significant period of time after the structural recombination in our data.

We observe 250 firms that exist in 1978 starting with letters A, B or C, and track them over the period 1978-1997. The industry breakdown consists of 181 medical device firms, 38 healthcare service firms, and 31 pharmaceutical firms. The minority of firms in the sample are acquisition active (34%) with an average of 1.4 acquired units, and have multiple business units (44%) with an average of 3.3 units. Most firms are not diversified (74% of firms) and the mean of medical to non-medical sales is 0.7. Most firms are domestic (90%) and the average age is 51 years. Of these 250 firms, they exit the sample over time such that there are 158 firms remaining in 1983, 132 firms in 1986, 117 firms in 1989, 98 firms in 1993, and 85 firms remaining in 1997. By then, 97 firms had been acquired and 68 had been shut down. The full sample of 250 firms includes a total of 866 unique business units over the course of the study period.

For this study, since our main construct of interest is structural recombination, we sample on the firms that have multiple business units, are reconfiguration-active, survive for at least two time periods (to include lagged terms), and for which patent data is available. This sampling reduces our sample from 250 firms to 71 firms. Of these remaining 71 firms, within one time period the average amount of reconfiguration is 1.26 events. The firms had an average (non-logged actual value) of 14,000 employees and almost $611 million in medical sales.
Measures

Dependent variable

Our dependent variable for all hypotheses is firm innovation in a period. The variable ‘Innovation’ is measured as the change in the citation-weighted patent stock for a firm from time ‘t’ to ‘t+1’. Patents are counted in the year that they are applied for, though only patents that are eventually granted are included in our measure. Following Hall, Jaffe and Trajtenberg (2005) we use an annual discount rate of 15% to create a stock measure of patents. Thus, the value of patent stock in any year is the sum of the number of patents applied for in that year and the stock of patents in the previous year discounted by 15%. Moreover, because patents may vary in their value (Griliches 1990; Trajtenberg 1990b; Ahuja and Lampert 2001), we weight each patent by the number of citations it receives from other patents. This is done by first adjusting the citations received by the patent by the average citations received by any patent in that same year and within that same patent class\(^2\) (to account for differences in citation rates across patent classes and cohorts), and then multiplying the patent by this (adjusted) number of citations. The use of citation weights is a common feature in innovation literature, as is the adjustment of citation counts to account for cohort and patent class (Hall et al., 2001; Hall et al., 2005). In addition, weighting patents by citations means that we are closer to measuring the value of the knowledge generated by the firm. Since we measure the change in patent stock, the measure captures how innovative a firm has been during the period, or the extent of new knowledge it has created.

Independent variables

Our main independent variable is the amount of firm structural recombination during a period. The variable ‘Recombination’ is a count, for a firm, of the number of events in which a

\(^2\) We use four-digit IPC classes as our measure of patent class
business unit was merged into another business unit (thus losing its original identity) for the
lagged time period ‘t-1’ to ‘t’.

The variable ‘Technology Capability’ is, for a firm in a given period, the average number of
citations it has received per patent, where the number of citations is adjusted for the average
citations in the focal patent’s year and patent class. This measure is similar to what others have
used in past papers as indication of innovative impact or quality (Fleming 2001; Ahuja and
Lampert 2001; Rosenkopf and Nerkar 2001; Nerkar 2003; Miller, Fern and Cardinal 2007;
Makri, Hitt and Lane 2010). In essence, it measures the average value of the firm’s patents
relative to other patents in the same year and patent class. Thus, a technology capability measure
of ‘1’ means that the firm’s patents are, on average, neither more nor less valuable than the
patents of other firms in the same technology areas. Values greater than 1 imply that the firm’s
patents are, on average, more valuable than those of other firms, while a value less than 1 implies
that they are less valuable.

‘Technological Coherence’ captures average relatedness of a firm’s patent portfolio in a
given period. To calculate this measure, we first construct a measure of relatedness between
patent classes by calculating the number of citations between patents in the two classes as a
proportion of the total citations by patents in either class. We then compare each patent in the
firm’s portfolio to every other patent in the portfolio and calculate the average relatedness of that
patent to all other patents in the firm’s portfolio based on the patent class that it belongs to. This
measure is then averaged across all patents to give us a measure of overall technological
coherence for the firm, as expressed in Equation 1 below. Mathematically:

\[
\text{Coherence} = \frac{\sum p_i p_j r_{ij}}{\sum p_i \cdot \sum p_j}
\]

(Equation 1)

\(^3\) Ahuja and Lampert (2001) specifically examined firms’ breakthrough inventions and thus observed the top 1% of
an industry’s citation-weighted patents.
**Control variables**

We include a number of controls. First, because our dependent variable is the change in patent stock, we control for the level of a firm’s patent stock at time ‘t’. This calculation of this measure is described in the dependent variable section above.

Second, while our theoretical focus is on the coherence of the firm’s technological portfolio rather than its technological breadth per se, we include a control for the firm’s technological diversity. Consistent with prior work (Gambardella and Torrisi, 1998; Garcia-Vega, 2006; Wadhwa and Kotha, 2006) we measure technological diversity as one minus the Herfindahl index of firm patenting across patent classes.

There are also several firm-level controls included in the models at time ‘t’. ‘Employees’ is the natural log of the number of employees at the firm. ‘Medical Sales’ is the natural log of the

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4 In the models presented below coherence is scaled by a factor of a 100 to make the coefficients easier to interpret.
monetary sales of the firm (in thousands). ‘% Medical’ is the ratio of the firm’s medical sales to its total sales, and indicates extent of non-diversification (i.e. increasing amounts indicate activity predominantly in the medical sector). ‘Firm age’ is the number of years since the firm was incorporated. ‘Acquired Units’ is a count of the number of acquired business units at the firm; this controls for the level of a firm’s acquisition activity. Finally, ‘Employment Growth’ controls for the percentage change in the firm’s number of employees between ‘t-1’ and ‘t’ to account for the possibility that restructurings may be accompanied by downsizing.

Table 1 provides summary statistics and correlations for our sample.

*** Table 1 about here ***

**Methodology**

Given the panel nature of our data, as well as the continuous nature of our dependent variable, we use fixed effects panel regressions (xtreg in STATA) with fixed effects for both firm and year. Since we are interested in the effect of structural recombination on subsequent innovation, and on the moderating role of pre-recombination technological capabilities, we use a lagged structure, predicting change in patent stock between t+1 and t as a function of structural recombination between t-1 and t, and technological capability and coherence at t-1. The basic equation (see Equation 2 below) represented by model is:

\[
\text{Change in Patent Stock}_{t\rightarrow t+1} = \alpha + \beta_1. \text{Recombination}_{t-1\rightarrow t} + \beta_2. \text{Recombination}_{t-1\rightarrow t} \ast \text{Technology Characteristics}_{t-1} + \beta_3. \text{Technology Characteristics}_{t-1} + \beta_4. \text{Patent Stock}_t + \beta. \text{Controls}_t + \gamma_i + \delta_t + \varepsilon
\]  

(Equation 2)
where $\gamma_i$ is a firm fixed effect, $\delta_t$ is a year fixed effect, and $\varepsilon$ is an error term.

One issue with this analysis is that our main explanatory variable, structural recombination, may be endogenous. In particular, firms may vary in their propensity to undertake structural recombination depending on the nature of their technological knowledge, as well as the size of their patent stock. To account for this possibility we run a first stage probit regression predicting the likelihood of recombination as a function of firm technology variables and the lagged values of the other controls in our main regression (i.e. their values prior to the structural recombination). Following Heckman (1971) we then calculate the inverse mills ratio from the predicted probability of recombination from this first stage regression, and include it as a control in our main models. The results for this first stage regression are reported in Appendix A. In addition to including all the independent variables from the second stage analysis, we also include a measure for the total number of units in the first stage to act as an instrumental variable, the logic being that, other things being equal, a firm with greater number of independent units is at greater risk for structural recombination, but need not be more innovative than another firm of the same size and technology characteristics.

A second issue with our analysis is the potential for autocorrelation, given that our dependent variable is the change in patent stock and we include patent stock as an independent variable. To ensure that our results are not biased by this problem, we run panel GLS models with first order panel autocorrelation (xtgls in STATA). Results from this alternate specification (not shown, but available upon request from the authors) are similar in direction and significance to those with our main models.
RESULTS

A glance at the correlation matrix in Table 1 reveals that firms’ patent stock is highly correlated with technological diversity and coherence as well as firm size and age. Large firms (by number of employees) are positively correlated with older, more revenue generating, more acquisition active firms. In addition, technological diversity and coherence are negatively correlated. Because some of the correlations are high, we check for excess multicollinearity by examining variance inflation factors and condition indices for the variables in our models. Our tests do not indicate these to be problematic.

Table 2 reports our analysis. Model 1 includes only controls variables, and model 2 adds our main independent variable of structural recombination. The coefficient of structural recombination in model 2 does not support Hypothesis 1, which predicts a negative relationship between structural recombination and innovation. Although the coefficient is negative, as expected, it is not significant.

*** Table 2 about here ***

Model 3 then examines the moderating effect of technology capability, by including the interaction between structural recombination and technology capability. Model 3 indicates support for Hypothesis 2; in the presence of strong technological capabilities, structural recombination has a positive effect on innovation. This positive moderating effect is consistent with our arguments for the benefits of strong technology capabilities in terms of greater potential for recombination, more targeted recombination and search, and lower disruption following the structural change. Interestingly, model 3 shows a negative and marginally significant (10% with a two-sided test) coefficient for structural recombination, suggesting that once the countervailing

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5 The mean VIF for our main models is 2.43, with none of the VIFs for the individual predictors, nor the overall condition index of the model exceeding 30, suggesting that multicollinearity problems are not severe Belsley (1991) and Belsley et. al. (1980).
effect of technology capability is accounted for, the main effect of structural recombination is to disrupt subsequent innovation, as predicted.

Next, we turn our attention to technological coherence. Model 4 shows a positive and significant coefficient for the interaction between technological coherence and structural recombination, implying that firms with high coherence are likely to benefit from structural recombination, consistent with Hypothesis 3. Again, the main effect of structural recombination is negative and significant in model 4, suggesting that in the absence of technological coherence structural recombination may actually harm firm innovation. Model 4 thus provides strong support for the importance of relatedness of firm knowledge as a moderator of the effects of structural recombination on innovation. In the absence of technological coherence, structural recombination is, in fact, disruptive to firm innovation, in line with our main argument. In contrast, where technological coherence is high, structural recombination may help unlock the potential for knowledge recombination within the firm, leading to improved innovation performance following the structural change.

**Supplementary Analysis**

These ideas are further explored in models 5 and 6, which test the effect of technological coherence in firms with high and low technological diversity respectively. Because firms with limited technological breadth will tend to have greater technological coherence, one concern with the findings in model 4 is that they may simply capture a negative effect of diversity on innovation following structural recombination. Moreover, our theoretical arguments suggest that firms will see benefits from structural recombination if they are technologically diversified in coherent ways, but that the disruptive effects of structural change will be especially strong if they
are diversified into a number of unrelated technological areas. Models 5 and 6 therefore study how the effect of technological coherence varies with technological diversity.

Model 5 shows the results for the subsample of firms with above median technological diversity. The interaction between structural recombination and technological coherence is positive and significant in this model, implying that, in line with our theory, firms that are diversified in technologically coherent ways have the most to gain from structural recombination. At the same time, the main effect of structural recombination in model 5 is negative and significant confirming that structural recombination is disruptive to innovation in firms with highly diffuse knowledge. In contrast, neither the main effect of structural recombination, nor its interaction with technological coherence is significant in model 6, which shows the results of our analysis in the subsample of firms with below median diversity. This implies that coherence does not have a significant impact on the effect of recombination on innovation in technologically focused firms. A comparison of the coefficients of the interaction terms in models 5 and 6 (Paternoster et al., 1998), shows that the two coefficients are significantly different (Z=2.81, p<0.01).

Overall, these results are consistent with our arguments. Although the main effect of structural recombination in Model 2 is insignificant, we find support for both H2 and H3, with the effect of structural recombination being positively moderated by technology capability and technology coherence respectively. Moreover, once the moderating effect of these technology variables is accounted for, we see a negative and significant main effect of structural recombination, consistent with our arguments for the disruptive effects of structural change.

An alternate approach would be to include a three way interaction between structural recombination, technological coherence and technological diversity, but this would raise issues of multicollinearity and make the results hard to interpret. We therefore choose to adopt a split sample approach.
CONCLUSION

This paper aimed to study how structural recombination affects innovation, and how technological characteristics of firms’ knowledge base moderate this relationship. Although we find an insignificant effect of structural recombination on innovation overall, our analysis indicates the relationship between structural recombination and innovation is dependent upon the strength and coherence of the firm’s technological capabilities leading up to the structural change. For firms that have strong technology capabilities, and are either focused or diversified in technologically coherent ways, structural recombination can be an effective means to unlock the potential complementarities between knowledge resources in different parts of the firm. In contrast, where technological capabilities are weak, or where the firm is diversified into a number of unrelated technological areas, structural recombination has a negative effect of subsequent innovation. Interestingly, structural recombination has a stronger positive effect on innovation for firms that are coherent diversifiers than for firms with a narrow technology focus, highlighting the potential for recombinant innovation in coherent diversifiers.

These findings contribute to the existing literature in a number of ways. First, they shed new light on the consequences of structural change by examining the effect of structural recombination on innovation. While prior work suggests that structural recombination has a negative effect on innovation (Karim, 2009), our study goes beyond this average effect to examine the contingencies that moderate this effect, linking it to the strength and coherence of the firm’s knowledge resources. As such, our study provides a more nuanced perspective on the effects of structural recombination on innovation. In particular, our findings highlight the value of coherent diversification (Teece et al 1994; Breschi, Lissoni and Malerba 2003; Nesta and

---

7 Karim (2009) measures innovation as entry into new product lines, a measure that is both less granular and conceptually distinct from the patent based measures used in our study
Saviotti 2005), and suggest that structural recombination is most beneficial where a combination of strong capabilities and coherent diversification means that there are strong potential complementarities between a firm’s knowledge resources.

Second, the findings of our study contribute to the literature on technology innovation, highlighting the role of structural change as a means for firms to recombine their internal knowledge resources. While this kind of internal boundary spanning (Rosenkopf and Nerkar, 2001) has been frequently discussed in the literature (Galunic and Rodan, 1998; Miller et al., 2007), the focus of this work has been on the sharing of information between divisions within an existing structure (Verona, 1999; Jansen et al., 2005; Tortoriello et al., 2011). This study shows that another way in which firms can recombine its internal knowledge resources, and capture the potential complementarities between them, is by changing its structural reconfiguration and redrawing the boundaries between units.

The possibility of using structural change to enable knowledge recombination is important not only because it suggests an alternate way of realizing intra-firm complementarities in knowledge, but because knowledge recombination through structural change may offer certain advantages over inter-unit knowledge transfer. As several recent studies have pointed out, successful recombination of knowledge within the firm may require more than the simple transfer of knowledge from one unit to the other, it may require the translation and transformation of knowledge across semantic and pragmatic boundaries (Carlile and Rebentisch, 2003; Carlile, 2004). Knowledge transformation involves redefining and negotiating knowledge to create a collective solution (Carlile and Rebentisch, 2003), and requires both constant engagement between diverse technological domains, and the successful overcoming of political and incentive issues (Carlile, 2004; Kellogg, Orlikowski and Yates, 2006). One way for firms to
enable this kind of higher-order knowledge transformation may be by changing the structure of
the organization, thus helping to overcome the pragmatic boundaries between knowledge
domains. Firms that undertake such structural recombination risk disrupting their existing
technological capabilities, of course, but the findings of this study suggest that in the presence of
strong technological capabilities and technological coherence, structural recombination may be
an effective way of enabling knowledge transformation.

The findings of our study also extend the technology literature in other ways. While prior
work has examined the direct effect of technological strength (Fleming 2001; Ahuja and Lampert
2001; Katila and Ahuja, 2002; Nerkar 2003), breadth (Gambardella and Torrisi 1998; Ahuja and
Lampert 2001; Nesta and Saviotti 2005; Garcia-Vega 2006) and coherence (Breschi et al., 2003;
Nesta and Saviotti, 2005) on firm innovativeness per se, we show that these factors also have an
indirect effect by moderating the effect of structural change on firm innovation. These findings
also complement work in the corporate strategy literature that emphasizes the complementarity
between partner knowledge as a driver of innovation performance following an acquisition
(Cassiman et al., 2005; Makri et al., 2010) and alliances (Sampson, 2007). Our study suggests
that diverse yet complementary knowledge may be important to knowledge recombination not
only between organizations, but also within them.

Finally, our study informs the literature on organizational reconfiguration and change. A
number of recent studies have examined the role of organizational ‘patching’ or ‘reconfiguration’
as a means to extend and deepen firm resources, and therefore as an integral part of a firm’s
dynamic capability (Brown and Eisenhardt, 1997; Eisenhardt and Brown, 1999; Karim and
Mitchell, 2004). Our study contributes to this work by examining the important but relatively
underexplored effect of structural change on the firm’s innovation performance (Karim, 2009).
In addition to contributing to the literature, our study also has important implications for managers. Our results suggest that, in general, managers should be wary of pursuing structural recombination for fear of its effects on subsequent innovation. While the effect of structural recombination on innovation is not statistically significant in our main model, the negative sign of this coefficient suggests that, on average, changes in organizational structure are more likely to do harm than good to subsequent innovation. This may be especially true, moreover, for firms that have weak technological capabilities or that are diversified into multiple and unrelated technological areas. In other words, managers of firms with low quality and diffuse knowledge looking to kick-start innovation would be ill-advised to do so by changing their organizational structure. Instead, it is managers of firms with strong, focused and coherent technological capabilities, who may benefit from using structural changes to unlock the recombinant potential of their internal knowledge.

Our study could be improved in several ways. Controlling for the intent behind different recombinations would certainly be useful, or even knowing the financial performance at the business unit level, which would shed some light on intent. Further, we observe recombinations in three to four year windows of time due to the availability of the medical database; more granular annual data would capture even more recombinations that may have occurred within firms. We were limited to 250 firms in the full sample due to the intricate mapping of firms’ business unit reconfiguration evolution; a larger sample or looking at other industries outside of the medical sector could always serve as a good robustness check of our results.

In addition to these limitations, our study also suggests several avenues for future research. While our study focuses on the effects of structural recombination, the contingent effects highlighted here may have relevance to other forms of recombination, including combinations of
internal and external knowledge, and recombination of internal knowledge through inter-unit collaboration. Future work could examine how these other means of recombinant innovation are affected by the strength and coherence of firm knowledge. Future work could also examine how these factors impact the acquisition and divestment decisions of the firm, as well as the decisions on structural changes accompanying these corporate transactions.

In summary, our study examines the effects of structural recombination on subsequent firm innovation, and the moderating role of the firm’s technology characteristics in this context. For firms with weak and diffuse technological capabilities, structural recombination results in a disruption of their existing routines and capabilities, causing subsequent innovation to decline. By contrast, where a firm has strong technological capabilities or where it is technologically diversified in coherent ways, structural recombination can help unlock the potential for intra-firm knowledge recombination, resulting in innovation improvement. These findings extend our understanding of organizational reconfiguration and change, highlighting the contingent nature of the effect of such change on firm innovation. They also contribute to the literature on intra-firm knowledge transfer, suggesting that structural recombination may be an alternate way to unlock the potential for knowledge recombination within the firm.
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FIGURES

Figure 1
Example of Structural Composition and Structural Reconfiguration at J&J, Inc.

By 1975
Codman & Shurtleff, Inc. (acquired pre-1975)
Kees Surgical Specialty (acquired 1987)

By 1986
Applied Fiberoptics (acquired 1982)
J&J Orthopedics, Inc. (internally developed 1986)
Codman & Shurtleff, Inc.

By 1989
By 1986 recombine AF into CS.
By 1989 recombine KSS into CS.

By 1993
By 1993 recombine CS and J&J Ortho into new J&J Prof.

J&J Professional, Inc. (created from recombination 1993)

Legend:
- Entry into J&J
- Internally developed unit (I)
- Acquired unit (A)
- Mix of I units
- Mix of A units
- Mix of A and I units
**Table 1**

Summary Statistics & Correlation Matrix

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<th>11</th>
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<tr>
<td>Patent Stock (citation-weighted)</td>
<td>186.44</td>
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<td>2099.68</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Recombination (t-1)</td>
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<td>3.43</td>
<td>0.00</td>
<td>26.00</td>
<td>0.37</td>
<td>1.00</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>1.00</td>
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<tr>
<td>Technology Coherence</td>
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<td>1.00</td>
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<tr>
<td>Technological Diversity</td>
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<td>0.00</td>
<td>0.97</td>
<td>0.39</td>
<td>0.21</td>
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<td></td>
</tr>
<tr>
<td>Employees</td>
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<td>12.11</td>
<td>0.53</td>
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<td>-0.09</td>
<td>-0.44</td>
<td>0.49</td>
<td>1.00</td>
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<td></td>
</tr>
<tr>
<td>Medical</td>
<td>10.48</td>
<td>2.60</td>
<td>6.21</td>
<td>16.02</td>
<td>0.48</td>
<td>0.44</td>
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<td>-0.38</td>
<td>0.44</td>
<td>0.78</td>
<td>1.00</td>
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<td>% Medical</td>
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<td>1.00</td>
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<td>-0.25</td>
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<tr>
<td>Firm Age</td>
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<td>-0.19</td>
<td>-0.27</td>
<td>0.27</td>
<td>0.49</td>
<td>0.52</td>
<td>-0.40</td>
<td>1.00</td>
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<td></td>
</tr>
<tr>
<td>Acquired Units</td>
<td>1.42</td>
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<td>17.00</td>
<td>0.36</td>
<td>0.56</td>
<td>-0.13</td>
<td>-0.23</td>
<td>0.28</td>
<td>0.55</td>
<td>0.54</td>
<td>-0.33</td>
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<tr>
<td>Employee growth</td>
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<td>0.42</td>
<td>-1.00</td>
<td>3.64</td>
<td>-0.09</td>
<td>-0.04</td>
<td>0.05</td>
<td>-0.01</td>
<td>0.08</td>
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<td>-0.03</td>
<td>0.19</td>
<td>-0.19</td>
<td>-0.07</td>
<td>1.00</td>
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Table 2
Main Results

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<th>Technological Diversity</th>
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<tr>
<td></td>
<td>High</td>
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<tr>
<td>1</td>
<td>2</td>
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<tr>
<td>Recombination (t-1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Recombination x Technology Capability</td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Recombination x Technology Coherence</td>
<td></td>
</tr>
<tr>
<td>Technology Capability</td>
<td>-36.06</td>
</tr>
<tr>
<td></td>
<td>(30.62)</td>
</tr>
<tr>
<td>Technology Coherence</td>
<td>-0.57</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
</tr>
<tr>
<td>Patent Stock (citation-weighted)</td>
<td>-0.37*</td>
</tr>
<tr>
<td></td>
<td>(0.14)</td>
</tr>
<tr>
<td>Technological Diversity</td>
<td>33.75</td>
</tr>
<tr>
<td></td>
<td>(41.10)</td>
</tr>
<tr>
<td></td>
<td>(13.35)</td>
</tr>
<tr>
<td>Medical</td>
<td>-15.30</td>
</tr>
<tr>
<td></td>
<td>(24.15)</td>
</tr>
<tr>
<td>% Medical</td>
<td>40.33</td>
</tr>
<tr>
<td></td>
<td>(86.16)</td>
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<tr>
<td>Firm Age</td>
<td>-2.03</td>
</tr>
<tr>
<td></td>
<td>(2.19)</td>
</tr>
<tr>
<td>Acquired Units</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>(6.90)</td>
</tr>
<tr>
<td>Employee growth</td>
<td>47.17</td>
</tr>
<tr>
<td></td>
<td>(38.58)</td>
</tr>
<tr>
<td>Inverse Mills</td>
<td>-53.15</td>
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<tr>
<td></td>
<td>(87.55)</td>
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<tr>
<td>N (firms)</td>
<td>212</td>
</tr>
<tr>
<td></td>
<td>(71)</td>
</tr>
<tr>
<td>R-square (within)</td>
<td>0.302</td>
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<tr>
<td>Model Comparison</td>
<td>[2]-[1]</td>
</tr>
<tr>
<td>F-test (model improvement)</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Dependent variable is change in patent stock between t and t+1. All models include firm and period fixed effects, as well as a constant term. Figures in parentheses are robust standard errors. High and low technology diversity refers to values of technology diversity above and below the sample median respectively. All models have Prob>F less than 1%. Significance level (two-sided): †<10%, *<5%, **<1%, ***<0.1%
Appendix A  
First Stage Prediction Model

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Capability</td>
<td>0.32</td>
<td>(0.28)</td>
</tr>
<tr>
<td>Technological Coherence</td>
<td>0.00</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Patent Stock (citation-weighted)</td>
<td>0.00†</td>
<td>(0.00)</td>
</tr>
<tr>
<td>Technological Diversity</td>
<td>-0.11</td>
<td>(1.27)</td>
</tr>
<tr>
<td>Employees</td>
<td>0.12</td>
<td>(0.10)</td>
</tr>
<tr>
<td>Medical</td>
<td>0.02</td>
<td>(0.11)</td>
</tr>
<tr>
<td>% Medical</td>
<td>-0.76</td>
<td>(0.57)</td>
</tr>
<tr>
<td>Firm Age</td>
<td>0.01†</td>
<td>(0.00)</td>
</tr>
<tr>
<td>% Acquired Units</td>
<td>0.35</td>
<td>(0.67)</td>
</tr>
<tr>
<td>Total Units</td>
<td>0.15*</td>
<td>(0.07)</td>
</tr>
<tr>
<td>Recombination (lag)</td>
<td>0.04</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Employee growth</td>
<td>-0.49</td>
<td>(0.56)</td>
</tr>
</tbody>
</table>

N 212  
Chi-square 37.01***

Random-effects probit model. Dependent variable is dummy variable that takes the value 1 if the firm undertook any structural recombination between t and t+1, 0 otherwise. Independent variables are measured at t, except recombination lag, which is measured between t-1 and t. Model includes constant term. Figures in parentheses are robust standard errors. Significance level (two-sided): †<10%, *<5%, **<1%, ***<0.1%