Does the Market for Ideas Influence the Rate and Direction of Innovative Activity: Evidence from the Medical Device Industry[1]

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ABSTRACT

Technological progress is an important driver of economic growth. The process by which technologies are conceived and developed is therefore of critical importance to scholars. Prior work argues that the "market for ideas" supports the division of innovative labor, which allows efficient utilization of technology and leads to welfare gains. Although this literature has usefully described the characteristics of this market and how they shape participants' decisions, the question regarding how the market influences the rate and direction of aggregate innovative activity remains open. We exploit an exogenous shock to a subset of firms in the U.S. medical device industry to study this question empirically. We first document the breakdown in the market for ideas after a U.S. Department of Justice investigation in 2005 made working with the five leading orthopedic firms more difficult for physician-inventors. We then find evidence of a dramatic decline in the rate of innovation at the firm and industry level. In addition, a marked shift in direction occurs toward lower-quality inventions and away from product categories in which downstream firms historically relied more heavily on physician knowledge inputs, most notably spinal implants.

Keywords: market for ideas, market for technology, open innovation, health care, innovation strategy

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Introduction

The link between technological progress and economic growth has spurred significant research into the organization of innovation. Influential prior work has emphasized the importance of a well-functioning market for ideas[2] (Gans, Hsu, and Stern 2002; Gans and Stern 2003), which provides the opportunity for inventors to commercialize their ideas through cooperation with incumbent firms as an alternative to entering the product market directly (Audretsch 1995, Winter 1984). Research in this area emphasizes the importance of both ex-ante and ex-post contracting mechanisms (Arora et al. 2004; Arora and Gambardella, 2010) to help facilitate the flow of ideas across organizational boundaries, often referred to as open-innovation strategies (Chesbrough 2003, Laursen and Salter 2006, Dahlander and Gann 2010). Through the division of innovative labor among specialized parties (Arora and Gambardella 1995), technology can be developed more efficiently, diffused more quickly, and utilized more effectively due to gains from trade, presumably leading to welfare gains. This literature has shown that characteristics of the market for ideas influence important outcomes such as the timing and frequency of licensing (Gans et al. 2008) and inventor commercialization decisions (Gans, Hsu, and Stern 2002). However, we know little about the impact of the market for ideas on the rate and direction of innovative activity and, ultimately, social welfare. Without this link, the fundamental importance of the underlying markets for ideas is not fully apparent.

In this paper, we first document an exogenous shock that disrupts the market for ideas by adding frictions to collaborations between inventors and an important subset of firms. Next, we demonstrate how these frictions influence downstream product innovation at the firm and industry level. We find that when the market for ideas breaks down, the rate of innovative activity slows dramatically. In addition, the direction of innovative activity shifts toward lower-quality inventions and away from product categories in which downstream firms historically relied more heavily on physician knowledge inputs, most notably spinal implants. These results provide some of the first empirical evidence that the functioning of the market for ideas influences both the rate and direction of innovative activity.

We use a series of events in the U.S. medical device industry as our empirical setting. In 2005, the U.S. Department of Justice (DOJ) investigated the five leading orthopedic device companies (accounting for between 93% and 95% of yearly sales of artificial hips and knees (Healy and Peterson 2009)) regarding their close relationships with physicians. The medical device industry has long been characterized by collaborations between physicians and firms, and prior work has demonstrated that physicians contribute valuable knowledge to corporate inventions and products (Chatterji and Fabrizio

[2] While the literatures on the market for ideas (Gans, Hsu and Stern, 2002; Gans and Stern, 2003) and the market for technology (Arora et al. 2004; Arora and Gambardella, 2010) have evolved somewhat distinctly, they address similar issues. For the purposes of our paper, we use the term "market for ideas" to incorporate the insights of both of these influential literatures.

2012). The purpose of the legal action was to address potential conflicts of interest presented by physicians that receive payments from orthopedic device firms while also being in a position to recommend their products to patients. However, this investigation also introduced significant frictions to a previously robust market for ideas and made open-innovation strategies more challenging.

We first document the breakdown of the market for ideas using data on the number of physician-invented patents assigned to companies each year. We find a precipitous drop in the likelihood that a physician-invented patent is assigned to one of the five firms during the investigation and subsequent settlement period, relative to a set of similar firms. We then examine the pattern of product-innovation outcomes, and find evidence of a large decline in FDA-approved products for the firms under investigation. These changes occur despite the fact that these firms continue to invest in R&D at rates similar to the period before the investigation. Although a significant increase occurs in product approvals for new ventures entering the market, innovation by these new entrants and other incumbents not under investigation does not compensate for the drop in innovation by the five firms targeted by the DOJ. Thus the aggregate rate of innovation in the industry declines when frictions are introduced to the market for ideas. To our knowledge, this empirical study is the first to establish a direct connection between the market for ideas and product innovation at the firm and industry level.

Finally, we examine how the direction of innovation changes after the disruption of the market for ideas. Based on the evidence from patented inventions, we see the largest decreases in both the number of inventions and the average quality of inventions in the technology areas where physician co-patenting with companies declines the most. Moreover, the largest decreases in the number of FDA-approved products generated by the five companies under investigation occurred in product areas related to prosthesis and spine. The investigation did not significantly affect surgical instruments and fixation devices. This result matches the pattern of the pre-investigation relative reliance on physicians to develop products in these categories. Our findings provide the first evidence that the market for ideas crucially shapes the direction of innovation and product development.

Our work makes both theoretical and empirical contributions to the academic literature on strategy and entrepreneurship. Our analysis represents one of the few empirical tests of an influential body of work related to the market for ideas and open innovation (Teece 1986; Gans et al. 2002, Gans and Stern 2003, Chesbrough 2003, Arora et al. 2004). Our empirical approach involves careful consideration of event timing, the relevant control group of firms, and clear product-innovation measures. Finally, our outcome measure, downstream product innovations, moves this literature closer toward considering the impact of the market for ideas on product markets and ultimately social welfare. Our results suggest the market for ideas facilitates important transfers of knowledge and technology that lead to innovations that would not otherwise exist.

The next section briefly reviews the theoretical and empirical work on the market for ideas. We note that there is little robust empirical evidence for how this market influences the rate and direction of product innovation. The third section provides the details on our empirical context. The fourth section describes the empirical methodology, including the data and variables. The fifth section reports the results of the empirical analysis, and the final section reviews implications for the academic literature and practice.

The Importance of the Market for ideas

Theory on the Market for ideas

Using insights from the prior literature (Teece 1986, Gans et al. 2002, Gans and Stern 2003, Arora et al. 2004, Fosfuri 2006, Arora and Gambardella 2010), we seek to understand how the market for ideas influences the rate and direction of innovation at the firm and industry level. The functioning of this market allows firms to engage in open-innovation strategies (Chesbrough 2003), searching for ideas outside of organizational boundaries, whether from other incumbents, new entrants, product users, or suppliers. The introduction of frictions into the market for ideas (c.f. Agarwal et al. 2013), makes open-innovation strategies more difficult and negatively impacts potential sellers' incentives to generate ideas in the first place (Arora et al. 2004).

The market for ideas literature makes predictions about the key characteristics of these markets and how they influence incentives to transact. However, what prior work has left unexplored is how the market for ideas influences the rate and direction (Arrow 1962; Fellner 1966) of product innovation, a key outcome of interest. As Arora and Gambardella (2010: 642) state, the "area in the most urgent need of attention is research on the consequences of the market for technology, on the rate and direction of inventive activity, and on productivity growth." Below, we synthesize insights from prior work to generate predictions about the impact of this market on the rate and direction of innovation.

The Rate of Innovation

The theoretical and empirical work on the market for ideas is broadly concerned with the factors that shape decisions upstream and downstream, typically the likelihood of licensing a technology versus entrepreneurial entry by an inventor. In particular, the prior literature posits three key factors that influence the inventor's commercialization mode: the strength of intellectual property protection, the availability and importance of complementary assets, and bargaining costs between inventors and incumbent firms (Teece 1986, Gans et al. 2002, Gans and Stern 2003). Gans et al. (2002) provide empirical evidence that stronger intellectual property-rights protection, greater importance of complementary assets, and lower bargaining costs are associated with inventor cooperation with

incumbents, rather than independent development of innovations, based on cross-sectional analysis of a survey of venture-backed and SBIR-backed start-ups across multiple industries.

Other empirical work also demonstrates that frictions in the market for ideas shape inventor and incumbent decisions. Gans et al. (2008) document how uncertainty associated with the United States Patent and Trademark Office's (USPTO) delay in granting a patent introduces frictions in the market for ideas, ultimately influencing the timing of cooperative licensing agreements. Agarwal et al. (2013) find that different market characteristics (thickness, bargaining frictions, and safety (see Roth 2007, 2008)) impact the likelihood of licensing, and this effect varies depending on the stage in the licensing process.

These studies support the view that a well-functioning market for ideas creates opportunities and incentives for specialization and gains from trade (Lamoreaux and Sokoloff 2001; Arora and Ceccagnoli 2006). When downstream owners of important complementary assets and a well-functioning market exist, the incentives for upstream actors and others to specialize in generating ideas and licensing to downstream incumbents are stronger. The market also encourages specialization of downstream players (e.g., pharmaceutical firms with large sales forces who rely on upstream biotech suppliers) and potentially even entry by new downstream firms, depending on industry structure. Taken together, the presence of specialized firms upstream and downstream should result in greater efficiency in the innovation process and a higher rate of new innovations compared to a scenario where the market for ideas is not functioning well. Prior empirical work finds that the presence of a market for ideas is correlated with increased specialization of labor (Lamoreaux and Sokoloff 2001) and increased downstream entry (Lieberman 1989, Arora et al. 2001).

In addition, empirical evidence suggests that when downstream firms can access external knowledge, they are likely to develop more innovations. This work has found that external knowledge sourcing is positively related to the rate of corporate invention (Shan et al. 1994, Cockburn and Henderson 1998, Rosenkopf and Nerkar 2001) and innovation (Laursen and Salter 2006, Chatterji and Fabrizio 2013). It is important to note that this work has looked at knowledge flows more generally, not only in the context of the market for ideas. These papers typically look at firm-level measures of invention and innovation and do not provide counterfactuals for how these outcome measures would change in the absence of external knowledge flows. Thus, although this work effectively demonstrates that firms sourcing knowledge externally have superior performance, they do not shed much light on the aggregate rate and direction of innovation. One exception is Moser and Voena (2012), which finds that compulsory licensing of patented inventions increases the number of new follow-on inventions, exploiting variation across technology areas created by the 1917 *Trading with the Enemy Act* in the U.S.

Most of these papers focus on patents, not downstream product introductions. This distinction is important because changes in the market for ideas could influence a firm's ability and incentives both to

invent new technologies and to translate inventions into product innovations. Bloom et al. (2013) suggest that the technology space (patents) should be analyzed separately from the product market space. In other words, patent-based measures do not fully capture the impact of the market for ideas on innovation at the firm or industry level. Although at least two papers do consider the impact of external knowledge on product outcomes, they either provide cross-sectional evidence (Laursen and Salter 2006) or do not consider what happens when the market for ideas is closed off (Chatterji and Fabrizio 2013).

In sum, the empirical evidence on the market for ideas has thus far been focused on how market characteristics influence inventor and firm decisions related to licensing and entry, as opposed to the rate of innovation at the firm and industry level, an arguably more important outcome. Although Arora et al. (2004:10) argue that when the market for ideas is functioning well, "new technologies would be more likely to be developed," this proposition has not been tested systematically.

In our setting, we will explore how the rate of firm and industry innovation changes when frictions (c.f. Agarwal et al. 2013) in the market for ideas increase. When frictions increase, upstream specialists have weaker incentives to develop new ideas in the first place and are more likely to require their own costly downstream assets to commercialize their inventions. For their part, downstream firms will, at least in the short term, have difficulty replacing the ideas provided by upstream suppliers. In additton to these limitations, even if firms could expand vertically, the gains from trade are compromised. These forces lead to the prediction that increased frictions in the market for ideas will decrease the rate of innovation at the firm and industry level.

The Direction of Innovation

Whereas the prior literature on the market for ideas implies that a well-functioning market will have a positive impact on the rate of innovation, predicting the influence on the direction of innovation is more challenging, though likely just as important. If these markets allow the development of innovations that would not otherwise have been created, the welfare benefits could be considerable. However, to our knowledge, prior empirical work has not documented the relationship between the market for ideas and the direction of innovation at the industry level.

When frictions increase in the market for ideas, upstream idea specialists and downstream firms could potentially alter their activities and seamlessly adjust to new conditions. Upstream organizations could enter the downstream market directly to commercialize their ideas, acquiring the necessary complementary assets. Similarly, downstream incumbents could shift to developing ideas in house rather than relying on upstream suppliers. With these adjustments, the aggregate direction of innovation would remain unchanged.

However, in most empirical settings, including the medical device industry, this scenario is unlikely. First, downstream complementary assets (e.g., sales forces, regulatory expertise, etc.) are typically costly to acquire, concentrated among large downstream incumbents, and take substantial time to develop. Direct commercialization by upstream specialists, especially in the short term, is thus challenging. Moreover, without a well-functioning market to facilitate transactions, the incentives for upstream suppliers to develop ideas in the first place are weaker. Therefore, commercialized products based on ideas from upstream specialists will become scarcer, shifting the direction of innovation away from areas that rely on these specialists.

Second, prior work suggests downstream incumbents are unlikely to pivot quickly to developing ideas in house that the market for ideas previously supplied. The literature on local search argues that firms tend to search for new ideas in domains where they already have significant experience (March and Simon 1958, Levitt and March 1988, Rosenkopf and Nerkar 2001). This tendency creates "inertia" that makes firms unlikely to quickly identify and execute new opportunities (Hannan and Freeman 1984, Tushman and Anderson 1986, Henderson and Clark 1990, Tripsas and Gavetti 2000). Moreover, the literature on user innovation suggests product users will acquire specific knowledge through repeated use that will be distinct from firm knowledge and difficult for incumbent firms to replicate (von Hippel 1988). Based on these limitations, it is unlikely that downstream firms will be able to adjust quickly to replace the contributions of upstream specialists, especially if they are product users. Instead, downstream firms will be more likely to develop innovations that do not require such knowledge, thus shifting the direction of firm-level innovation toward areas more dependent on their own internal knowledge.

Further, as downstream firms turn inward and access less external knowledge, a significant academic literature suggests their inventions will be of lower quality and more incremental (Rosenkopf and Nerkar 2001; Lacetera 2009; Chatterji and Fabrizio 2012, 2013). Decreasing the use of external knowledge diminishes the likelihood of recombination between existing firm knowledge and novel knowledge from the outside, reducing the likelihood of breakthrough inventions (Fleming 2001). Thus not only will downstream firms do less of the innovation that upstream specialists previously powered, they will also focus on more incremental advances for their existing products.

Taken together, these dynamics suggest the direction of innovation at both the firm and industry level will move markedly away from the technology areas reliant on the contributions of upstream idea suppliers when the market for ideas breaks down. In addition, the subsequent inventions by downstream firms will be of lower quality.

Empirical Setting: The DOJ Investigation of the U.S. Orthopedics Industry

The medical device industry is an ideal context for testing theories about the market for ideas. First, the market conditions that favor cooperation with incumbent firms for commercialization (as specified by the market-for-ideas literature) hold consistently across this industry. Patents on inventions provide strong intellectual-property protection in the medical device industry (Cohen et al. 2002). Furthermore, complementary assets, including manufacturing expertise, knowledge of the regulatory approval and reimbursement procedures, marketing, sales and distribution capabilities, and relationships with doctors, are all held by established medical device firms and are costly to replicate. Finally, medical device firms have invested in developing close relationships with physician-inventors to facilitate knowledge transfer, reducing frictions in the market for ideas. If previous theory is applicable, these conditions suggest medical device inventors would have an attractive option for cooperating with established firms rather than forming new companies to commercialize new inventions. Prior work would predict a robust market for ideas to support open-innovation strategies by incumbents in this industry.

Indeed, previous studies have empirically documented the important role of practicing physicians as inventors and entrepreneurs in the medical device industry (Chatterji et al. 2008, Chatterji and Fabrizio 2012, Smith 2008). Physicians contribute about 20% of the patented inventions in medical devices, and their inventions are, on average, more highly cited and more likely to be at the leading edge of new technologies (Chatterji and Fabrizio 2012). A significant portion of these physician inventions are assigned to incumbent firms, reflecting the fact that physicians and medical device companies often work together to identify unmet clinical needs and develop successful products, exactly in the spirit of the market for ideas literature.

A transfer of ideas or technology between a physician and a medical device firm typically arise under one of two scenarios (Carlin 2004). First, a physician may collaborate with a firm to develop what becomes a co-invented patented technology. Alternatively, a physician may independently invent a technology and license it to an incumbent firm. These two scenarios map well to Arora and Gambardella's (2010) notion of ex-ante and ex-post contracting in the market for ideas, in this case occurring vertically through the value chain (from upstream inventors to downstream companies).

Company executives argue these interactions with physicians are essential to successful product development, because physicians are uniquely positioned to identify unmet needs, provide solutions other physicians would value and adopt, and offer insights into product attributes. Critics suggest the lucrative consulting arrangements can provide improper incentives for physicians to recommend a particular brand to hospital administrators and patients, irrespective of clinical evidence. A significant number of conflict-of-interest cases have involved orthopedic companies and surgeons, a market segment in which products are largely produced by five leading incumbents and brand loyalty is relatively high (Burns et al. 2009), arguably providing a significant barrier to competition and entry.

In response to these conflict-of-interest concerns, the DOJ launched an investigation proceeding on March 30, 2005, against the five largest U.S. orthopedic device makers, Biomet, the DePuy Orthopedics unit of Johnson and Johnson, Smith and Nephew, Stryker Orthopedics, and Zimmer. These companies comprised 93%–95% of sales in the hip and knee implant market in the United States (Healy and Peterson 2009). The investigation, which resulted in a criminal complaint, alleged that the companies violated the federal anti-kickback statue (Healy and Peterson 2009), in essence paying physicians to favor their own products in orthopedic procedures.

On September 27, 2007, a $310 million settlement was reached wherein four of the companies signed deferred prosecution agreements and one company (Stryker) signed a non-prosecution agreement, though notably none of the companies were required to admit guilt (Healy and Peterson 2009). Under these settlement agreements, the companies agreed to increase transparency with substantial new disclosures, including prominently posting on their websites any payments to physicians. The companies also agreed to substantial oversight, including a monitor appointed by the DOJ, and a compliance officer who would report to the Department of Health and Human Services Office of Inspector General. The settlement agreements also required the companies to develop prospective budgets and produce needs assessments that justified their collaborations with physicians. If the companies succeeded in satisfying the conditions of the agreement, the DOJ stipulated that the conditions of the prosecution agreements would expire in 18 months (March 30, 2009), although the corporate-integrity programs established with the Office of the Inspector General were to stay in place for five years, until September 2012 (Healy and Peterson 2009). According to media accounts, the settlement agreements had a dramatic impact on the operations of the companies involved (Healy and Peterson 2009). In our Empirical Methodology section below, we will describe in detail how we coded the investigation and settlement periods to estimate the "treatment effect" of this legal action.

While the companies reorganized their practices to satisfy the conditions of the settlement agreements, including disclosing information on payments to physicians, obtaining monitors, and fulfilling the other conditions of the agreements, "business as usual was suspended" (Healy and Peterson 2009: 1974). Payments to physicians, as well as funding for scholarships, grants, and research, were canceled or put on hold. Once practices were aligned with the requirements, any companies desiring collaborations with physicians had to first pursue a needs assessment, pre-certify the work, and ascertain a fair market value for the work performed by the physicians (frequently resulting in rates much lower than the ones physicians were accustomed to, causing complaints).

While there were other investigations and settlements regarding medical device industry practices after the 2005 investigation, these were far smaller both in terms of the market share of the implicated firms and the settlement amounts (See Healy and Peterson 2009 for further details). In our empirical

approach, we separate out the 5 leading orthopedic companies targeted simultaneously by the original DOJ investigation, because they accounted for approximately 95% of the hip and knee implant market and eventually paid collective fines in the hundreds of millions of dollars. All other orthopedic firms serve as a comparison group. If the original DOJ investigation produced a broader "chilling effect", we would not expect to find differences between these two sets of firms.

In sum, a byproduct of the DOJ investigation was that cooperation between orthopedic physicians and the 5 leading orthopedic device firms became much more costly and difficult for firms, directly increasing the frictions in the market for ideas. This shift impacted physician-inventors with ideas in the orthopedics sector. The investigation and settlement agreements did not prohibit licensing inventions from physicians, but they reduced companies' willingness to cooperate with physicians and increased the costs of working with physicians on an ongoing basis. Ongoing interaction, consultation, and transfer of "tacit" inventor knowledge (Elfenbein 2007) are often necessary to effectively develop and commercialize new technological inventions, so the increased difficulty and costs involved in working closely with companies also likely reduced the potential for physician-inventors to license new technologies to orthopedic firms. In sum, the DOJ investigation is expected to have added frictions to the market for ideas, disrupting open-innovation strategies for an important subset of firms, and subsequently slowing the rate and altering the direction of aggregate innovation.

Empirical Methodology

Two aspects of this context are critical for empirically identifying the impact of the market for ideas on the rate and direction of innovation. First, the DOJ investigation provides an exogenous shock to frictions in the market for ideas, specifically for transactions between physicians and the medical device firms under investigation. The frictions in the market, and the resulting decrease in cooperation between parties, are not endogenous to technology or market characteristics. Second, a natural control group exists to which we can compare the temporal patterns in innovation. The DOJ investigation involved five orthopedics companies. Physicians are active inventors in many medical device segments outside of orthopedics (Chatterji and Fabrizio 2012). We can therefore compare the pattern of collaborative patenting and innovation by the five firms under investigation to other firms within orthopedics, and also to firms in other medical device segments, to isolate the effect of the lawsuit from other unobserved factors that affect commercialization strategies in the medical device industry as a whole, such as economy-wide fluctuations, the availability of venture capital, and the strength of intellectual property rights. If the DOJ's actions also affected other orthopedics firms or medical device companies outside of the orthopedics segment, our results would be biased toward non-significance.

To document the breakdown in the market for ideas, we use patent data to explore the extent to which physicians working in the orthopedics area reduced collaborative innovation with the companies involved in the DOJ investigation. We estimated a difference-in-differences model exploring the likelihood that a given physician-invented patent was assigned to a company, and specifically to a company under investigation versus another medical device company. We explore whether the change in the likelihood of collaboration from pre-investigation to during the investigation was significantly different for the companies subject to the DOJ lawsuit, relative to other medical device firms, both within and outside of the orthopedics area. The benefit of this analysis is that we were able to control for persistent differences between the orthopedics segment and other medical device segments, differences between the companies under investigation and other orthopedic companies, and changes over time that are common across orthopedics and other segments.

We test our predictions regarding the rate and direction of innovation with several analyses using patent data and a database of FDA-approved products. In these analyses, we examine the number of patented inventions and FDA-approved product innovations generated by companies involved in the investigation, relative to other medical device firms, as well as the aggregate innovation output for the sector. We use pre-investigation information on the co-inventing by physicians and firms to establish the degree to which firms were relying on physician inputs to innovation in different technology areas, and to test whether the direction of innovation shifts away from technology areas with significant physician-inventor involvement. In addition, we use data on the number of forward citations received for each patented invention to evaluate whether companies in the lawsuit decreased the quality of their inventions, relative to other medical device firms.

Data and Measures

Table 1 summarizes the measures used in our analyses. Our first analysis relied on the evidence of collaboration between physicians and medical device firms available from the patent data. Because the DOJ investigation was fairly recent (beginning in March 2005), and granted patents only emerge two to three years after a patent application, we used data on both granted and not-yet-granted applications. Using the Delphion patent database, we selected all granted patents and patent applications for application years 2001–2010 in the technology classes the USPTO identified as medical device technologies (USPTO 2005). Our time period for analysis is necessarily truncated because the requirement to disclose applications only took effect in 2001, and applications are disclosed with an 18-month lag, so that many applications from 2011 were not yet public when the data were downloaded (October 23, 2012). For each patent (or application), we collected information including the technology class and subclass, the earliest priority date, the assignee, and the name (first, middle, and last) and address (city, state, and country) of

each inventor. Using the technology classifications provided by the USPTO, we identified which of these patents were for orthopedic inventions, and created an indicator variable, *Ortho*.

To identify physician-generated inventions, we relied on the American Medical Association (AMA) Masterfile data. The AMA Physician Masterfile contains the name, demographic information, address, history of prior locations, type of practice, and medical school information for all licensed U.S. physicians. With this information, we were able to match the inventor data to the AMA list of physicians and identify which inventors listed on our sample of medical device patents were physicians.

We performed this match in several steps. First, we identified any physicians with the same last name, first name, and state location as an inventor listed on a medical device patent. We used the physicians' historic and current locations listed in the AMA data and the inventors' addresses provided in the patent data for this match. After identifying possible matches, we evaluated them more closely to assure a true match. For each record, if a middle name or initial was available from both sources (the patent data and the AMA data), we verified that these records matched, and eliminated any for which they did not match. When one or both of the middle initial observations was missing, we verified that the observations matched by city. We flagged for manual evaluation observations lacking sufficient middle-name data that did not match exactly based on city. Based on this match, we created an indicator variable equal to one for patents that included at least one physician inventor, *DrPat*.

Because we are focusing on the market for ideas, we are using these co-inventions with physicians as an indicator that the physician is contributing intellectual capital to the company-assigned invention through collaboration. Given the multi-faceted relationships between physicians and medical device firms, however, one might be concerned that inventorship on a company patent could reflect a general consulting relationship, and not a true intellectual contribution to a specific technology. Differentiating between these two kinds of relationships is difficult using patent data alone. However, as a condition of the settlements, the firms were required to disclose additional information about the physicians with which they collaborated. DePuy's disclosure was unique in that it differentiated between various types of corporate-physician relationships from 2007-2010. We used the information that DePuy reported about contracts with 683 physicians from 2007-2010 to gain insight into the meaning of physician inventorship on a company patent (see Hockenberry et al. 2011 for additional details about this data).

Among the 683 physicians listed by the company in total, 10.4% are listed as an inventor on at least one DePuy-assigned patent. Of the 217 physicians DePuy reports paying for "IP or intellectual contribution to product development," 25% are listed as an inventor on company patents, and of the 94 physicians listed as providing "research support," 15% are listed as inventors. On the other hand, of those physicians listed only as being paid for "consulting," only 3% are listed as an inventor. Although these

data are limited to only one company over four years, they do provide some evidence that inventorship on a company patent maps most closely to providing intellectual contributions related to product development and research, and are less likely to be a reflection of pure consulting relationships.

Next, we also use the identification of physician-invented patents to calculate the change in physician co-patenting from before to after the DOJ investigation for each firm-technology class observation. The variable *ChngNumDr* is the number of patents by a firm in a particular technology class that are doctor invented before the DOJ investigation began less the number of patents by the firm in that same technology class that are doctor invented after the DOJ investigation began. This variable is coded such that a positive value represents a *decrease* in physician co-inventing in the firm-class-year.

The Delphion patent database includes unique company identifiers for all firms that are significant patenters (defined by Delphion as firms with an excess of 1,000 patents)[3]. In our sample of medical device patents, 44% of the patents are assigned to one of these companies. We use these data, and the information contained in the Thomson Innovation Corporate family tree, to identify all patented inventions of the five companies under investigation and to create standardized firm identifiers for the "large" companies in the data. We create an indicator equal to 1 for patents assigned to companies involved in the lawsuit (*SuitCo*). In some analyses, we use these firm identifiers to examine innovation outcomes over time within firm.

To evaluate the effect of the market for technology on product innovation, we use the database of FDA-approved medical devices with application dates between 2000 and 2010, available online from the U.S. FDA, Center for Devices and Radiological Health. We include devices approved through both the pre-market notification (510k) process and the more rigorous pre-market approval (PMA) process, and exclude all supplemental filings to avoid double counting innovations. These data include the name of the applicant company and date of application, as well as the FDA-assigned medical specialty area and product code.

We use the FDA-assigned medical specialty area to identify orthopedic innovations (all those applications with the "OR" medical specialty code for orthopedics), and use the FDA product codes to evaluate the technological area of the device. The OR medical specialty area contains 204 product codes with names such as "Prosthesis, Elbow, Constrained, Cemented" and "Bone Cement." We worked with an experienced orthopedic surgeon to develop a decision rule to create categories and classify the product codes within orthopedics. The six categories are Prosthesis, Spine, Fixation Devices, Surgical instruments, Bone biological augments and material, and Miscellaneous. The decision rule to categorize product codes is as follows: (1) Any device name including "prosthesis" is categorized as such; (2) any device name including "spine", "spinal," or "vertebra" is categorized as Spine; (3) any device name not in

[3] Note that we only restrict our sample to these firms in the analyses reported in Tables 5 and 6.

the prior two groups that includes "fixation" is categorized as Fixation Device; (4) device names describing a tool (i.e., "file" or "drill") are categorized as Surgical Instruments; (5) any device name including "cement" or describing devices and products to augment bone is categorized as Bone biological augments and material; and (6) the remaining 13 device product codes fall in the miscellaneous category. We also cleaned the data for all applications in the OR specialty code to develop standardized applicant firm names, to facilitate within-firm analysis and identify innovations attributable to the companies involved in the suit.

All of our analyses rely on identifying the "treatment" period associated with the DOJ lawsuit. The investigation began on March 30, 2005. We use this precise date to establish the beginning of the treatment period in the patent-level analysis of company assignment. In the analyses that utilize annual data (at the firm or firm-technology class level), we code the treatment period as beginning in 2005. Identifying the end of the treatment period is more challenging. As reviewed above, the investigation concluded on September 27, 2007, with the signing of settlement agreements. However, these settlement agreements set out dramatic changes to the operations of the medical device companies with respect to how they would work with physicians going forward, so while the uncertainty of the investigation period was resolved, the frictions in the market for ideas continued. The settlement period ended 18 months later, on March 30, 2009, when the DOJ allowed the deferred prosecution agreements to expire and dismissed the criminal complaints against the companies. However, the corporate-integrity agreements and increased monitoring continued through 2012. When, or even if, the increased frictions in the market for ideas were reduced is unclear. In the patent-level analysis of assignment, we will use March 30, 2009, as the end of the treatment period, and test the robustness of results to two alternatives for the end of the treatment period: truncating the analysis after March 2009 or maintaining the "treatment" through the end of the analysis at the end of 2010.

In the analysis of annual patent data, we truncate the data at March 30, 2009 and end the treatment period, and then aggregate the data to the annual level. In the analyses using annual FDA approvals, we analogously truncate the data at 2009 and continue the treatment period through 2009. Because product innovations will occur with some delay after interactions with physicians, treating all of 2009 as part of the treatment period is appropriate for the evaluation of FDA approvals.

[Table 1 Here]

Summary Statistics

Table 2 reports summary statistics for the dataset of medical device patents and FDA-approved products. Panel A reports summary statistics for the patent-level measures used in the analysis of patent assignment. Fourteen percent of the medical device patents in these years included a physician-inventor.

Eleven percent of medical device patents were in orthopedics technology classes. Sixty-one percent of the medical device patents were assigned to a company, whereas 2% were assigned to the five companies involved in the DOJ investigation[4]. Panel B reports the firm-technology class-year-level patent measures used in the analyses of the rate and direction of innovative activity. Note that there are more observations in this set of measures because an observation exists for every firm-technology class-year, even if the firm generated no patents in that class-year. *ChngNumDr*, the change in doctor patents from before the investigation until the investigation period in a technology class for a given firm ranges from -49 (an increase in physician patents of 49 in the firm-class) to 132 (a decrease in physician patents of 132 in the firm-class). For the companies involved in the DOJ lawsuit, the average of *ChngNumDr* is 1.03 and the standard deviation is 6.41.

[Table 2 Here]

Panel C reports the summary statistics for the outcome variables based on the FDA product-approval data, at the firm-year level. We include only innovations in the orthopedic specialty in our analysis. Unfortunately, innovation in areas outside of orthopedics do not constitute a useful control group to which we can compare orthopedic innovation, because the annual number of innovations outside of orthopedics follows a steeply declining trend extending back to at least 2000. Therefore, we compare the trend in the number of innovations within orthopedics from before the investigation with the number of innovations during the investigation and settlement periods, and compare the time trends of innovations generated by companies involved in the investigation to other companies active in the orthopedics product area. Note that when a firm does not have any innovations in a given year, both *# Innovations* and *# Product Codes* will be equal to zero. Figure 1 provides a graph of the number of FDA-approved products in the Orthopedics specialty class for companies involved in the DOJ lawsuit, other companies, and the total. Even from this graph, we see the number of innovations generated by companies in the lawsuit clearly decreased post-2005, while other companies continued on a trend of increasing the number of innovations produced annually, with the exception of a slight dip in 2009.

[Table 3 Here]

[Figure 1 Here]

Regression Results

Evidence from Collaboration on Inventions

Our first analysis examined the propensity for physician-inventors to collaborate with an existing medical device firm, by evaluating the likelihood that a physician-inventor's patent was assigned to a firm. Conceptually, this analysis is a difference-in-differences estimation, wherein we compare the change in probability of company assignment from pre-investigation to post-investigation for two groups of patents:

[4] Overall, these 5 firms account for approximately 16% of all orthopedic patents during this period.

physician-invented orthopedics patents and physician-invented medical device patents in other segments. We also compare the probability of assignment to one of the investigated companies before and after the investigation, relative to assignment to other medical device firms. This analysis is intended to provide evidence that the DOJ investigation was associated with a disruption in the market for ideas.

Using patent-level data on all medical device patents (granted and applications) with earliest priority dates during the 2000-2010 period, we estimated Probit models predicting the likelihood that a patent was assigned to a company, assigned to a company not involved in the DOJ lawsuit, or assigned to a company involved in the DOJ lawsuit, including indicators for whether the patent includes at least one physician-inventor (*DrPat*), whether this indicator interacted with the indicators for the period of the DOJ investigation (*DOJ*), and, where appropriate, whether the patent is in orthopedics (*Ortho*). We control for whether the patent is a granted patent (*Granted*) or an application, because applications are expected to be less likely to be assigned on average. We included year indicators to account for any common time trends that affected the overall percentage of medical device patents that were assigned to companies. We also included a full set of technology-class indicators, controlling for differences in the share of patents assigned to companies across technologies. We report robust standard errors in all regressions.

[Table 4 Here]

The results, reported in Table 3, demonstrate that the likelihood that a physician-invented patent was assigned to a company decreased during the DOJ investigation. As reported in columns (1) and (2), the likelihood of assignment of a given physician-invented patents to a company falls by approximately 11% during the DOJ investigation. However, the reduction in assignment is not limited to orthopedics, the technology area of the firms under investigation. In fact, the decrease in the likelihood of a physician-invented patent in the orthopedic classes being assigned to a company during the DOJ period is no greater than the decrease for physician patents in other classes during the DOJ period (see column 2). The estimated coefficient on the interaction of *Ortho* and *DOJ* is not significant, indicating the assignment pattern for orthopedics patents that were *not* invented by physicians was no different during the investigation period than in other years.

To further investigate the assignment of physician patents, we split the dependent variable into assignment to a company involved in the DOJ investigation and assignment to another company. Columns (3) and (4) in Table 3 report the results for assignment to companies not in the lawsuit. While the assignment of physician patents to these companies fell following the investigation (see column 3), the assignment of physician patents in the orthopedics area to these companies increased (column 4). This rise occurred despite the fact that orthopedics patents generally were no more likely to be assigned to these companies during the investigation period – only physician-invented patents were affected. Column (5) reports the results for assignment to companies involved in the investigation. Because the entire

company was involved, and these companies are predominantly patenting in orthopedics, comparing patent assignment within and outside of the orthopedics area would not be useful. Assignment of physician-invented patents to companies in the lawsuit fell by about 14% during the investigation period. This evidence collectively suggests the DOJ investigation was associated with less company assignment of physician-invented patents, especially to the major orthopedics companies involved in the suit. Some of the physician-invented orthopedic patents appear to have shifted from companies under investigation to other firms.

A possible concern is that we are not capturing the impact of frictions in the market for ideas on the upstream inventors' incentives to invent. If physicians responded to the DOJ investigation by electing not to pursue commercialization of an invention, not to patent an invention, or not even to expend effort inventing in the first place, such possibilities would not be evident from our analysis. Because our models estimate the likelihood that physician inventions were company assigned, an increase (or decrease) in the number of physician inventions could influence the likelihood of company assignment even if the number of company-assigned physician inventions did not change. To investigate this potential issue, we examined the annual number of orthopedic inventions with and without physician-inventors over time. Based on a regression of the number of physician-invented patents in a class-year on an indicator for the DOJ period, a control for the number of total inventions in the class-year, and technology-class fixed effects, the number of physician patents decreased by about 6% during the DOJ investigation (the estimated coefficient is marginally significant). We found no evidence that the temporal pattern of physician inventorship in orthopedics was different from that for other classes. This evidence is consistent with increased frictions in the market for ideas within medical devices generally, not limited to the orthopedics segment, as we saw with the analysis of company assignment of physician patents.

The final two columns of Table 3 provide robustness tests for the two alternative constructions of the treatment period. Column (6) reports the results truncating the analysis as of March 2009, when the settlement period ended, and Column (7) reports the results treating the remainder of 2009 and 2010 as part of the treatment period. The estimated coefficient on the interaction of the doctor-patent indicator and the DOJ treatment is slightly larger and highly statistically significant in both cases, confirming our results.

These results are consistent with the DOJ investigation increasing frictions in the market for ideas between physicians and medical device firms. The market for ideas appears to have been disrupted both for the firms in the lawsuit and for other firms, although some evidence suggests physician patents in orthopedics shifted from the companies in the lawsuit to other companies, which saw an increase in assignment of physician-invented patents relative to before the investigation period.

Rate of Innovation

We now turn to testing the first of our predictions, that the decline in the market for ideas associated with the DOJ investigation had a negative effect on the rate of innovation. Table 4 reports the results of regressions of the number of FDA-approved product innovations in the orthopedic specialty class at the firm-year level on indicators for companies involved in the DOJ lawsuit (*SuitCo*) and companies that were established as start-up ventures during the period of investigation (*New Venture*). The first column reports the results of a pooled cross-sectional estimation with year fixed effects. Although companies in the suit produced more innovations annually than other companies, the interaction with the indicator for the time period during the lawsuit (*DOJ*) illustrates the number of innovations by companies involved in the suit fell during this period. Columns (2) and (3) report results also including applicant firm fixed effects, so that the interaction of *SuitCo* and *DOJ* identifies the change in the number of innovations from before the investigation to after for companies involved in the suit. Results confirm the number of annual innovations by companies in the lawsuit fell following the start of the investigation, by about 43% relative to before the investigation began. In column 3, we include an indicator for an applicant that is a new venture, as identified based on venture capital investments compiled from Capital IQ and Venture Xpert (*NewVenture*) interacted with the *DOJ* indicator. Results indicate innovations by new ventures increased during the DOJ investigation, relative to incumbent firms' companies, as we would expect as the market for ideas with established incumbents erodes. This result is especially interesting in light of the results above that indicate a shift in orthopedic physician inventions from companies under investigation to other firms. These results provide strong evidence that the rate of innovation decreased for the companies involved in the DOJ lawsuit.

One possible alternative explanation for the reduction in innovation is that the companies involved in the lawsuit were responding to reduced access to markets or lower incentives to innovate when sales channels (through physicians) are inhibited, rather than the impact of the frictions in the market for ideas, in which case the firms would reduce investment in the invention and development of new devices, in anticipation of the lower returns to innovation. This alternative is not consistent with the evidence. As Figure 2 shows, the growth rate in spending on R&D by the companies in the lawsuit remains fairly constant from 2005-2009, with no evidence of a reduction in R&D investment[5].

[Figure 2 Here]

We cannot estimate a regression model to test whether aggregate innovation across all orthopedic firms fell during this period, because of a lack of a counterfactual. However, evidence from the graph of

[5] It is possible that firms could have reduced their investments in other areas beyond internal R&D, such as corporate venture capital deals or acquisitions, but any decline in these areas is unlikely to outweigh the growth in internal R&D spending we document here.

total FDA-approved products in this specialty is revealing (Figure 1). Innovation by companies involved in the suit drops dramatically; innovation by other companies continues on the same trend as before the suit with only a small dip in 2009. Importantly, we do not see a dramatic increase in innovation by companies not involved in the lawsuit (despite the fact that these firms saw an increase in physician co-invention during the investigation). The aggregate level of innovation in the orthopedics sector stops increasing year over year, as it had before the lawsuit, and instead flattens off and decreases slightly during the lawsuit period. This graphical evidence suggests innovation by other firms did not compensate for the reduction in innovation by the companies affected by the suit, resulting in an overall reduction in orthopedic innovations.

Direction of Innovation

We next explore the impact on the direction of innovation. We examine two outcome variables related to different dimensions of "direction." First, we conceptualize direction as the relative quality of inventive activity, and use the number of citations received by patents as a measure of the quality of the invention, as is common in the literature (Trajtenberg et al. 1997, Hall et al. 2005). Second, we quantify the reduction in physician inputs across technological space, and conceptualize direction as how inventive and innovative activity shifts across that space.

For the analysis of the quality of the patents, we create a measure equal to the number of forward citations received by each patent, as of the time of download. This number is sometimes called the "citation weighted patent count" in the literature (c.f. Hall et al. 2005). We aggregate this count, as well as the count of patents, to the firm-technology class-priority year level. The goal of the analysis is to test whether the "quality" of the patents falls where the market for ideas is inhibited. All models include firm-technology class fixed effects, to control for differences across technology areas and across firms, and year fixed effects, to account for common changes over time and the fact that more recent patents have had less time to receive citations, and therefore have fewer citations on average. Table 5 reports results.

[Table 5 HERE]

The citation-weighted patent count (column 2) and the average citations per patent (column 4) both decrease during the DOJ period, and decrease the most in firm-technology class pairs where firm co-patenting with physicians decreased the most during this period. The final column tests the robustness of these results to controlling for whether the patents were granted at the time of data collection, using the percentage of patents in the firm-class-year that were granted patents, and the results are unchanged. The average change in the number of doctor patents for the companies in the lawsuit is 1.03 (across firms and technology classes), with a standard deviation of 6.41. Therefore, for a one-standard-deviation reduction in physician patenting in a technology class among the companies in the lawsuit, the number of citations

received by patents in that technology class declines by 8%, and the average number of citations per patent declines by 4%. This evidence is consistent with the prediction that the quality of patents declines where the market for ideas is restricted.

Our evaluation of changes in the technological space of invention and innovation is based on analyses of both patents and FDA-approved products. Before discussing the regression analysis results, an examination of the distribution of patents across orthopedic technology classes for companies involved in the lawsuit relative to other companies is instructive. Figure 3 displays a graph of the distribution of orthopedics patents across the top 15 technology classes for the patented inventions of companies involved in the lawsuit (Panel A) and other companies (Panel B) that were invented before the investigation began. The stripped and black-filled bars indicate technology classes that were no longer in the top 15 classes of the distribution for inventions after the investigation. Several observations are worth noting. First, firms involved in the lawsuit exhibit more of a "reshuffling" of inventive activity: four technology classes drop from the top 15 before the investigation to out of the top 20 after, and two drop from the top 15 to the top 20 (but not top 15). Only four classes fall out of the top 15 for the comparison group of companies. In addition, the classes that are reduced in frequency for the companies in the investigation are more prevalent in the pre-DOJ period, relative to those classes that are reduced in frequency for other companies. Finally, note that four of the technology classes in which companies in the investigation reduce invention are related to spine inventions (606246, 62301713, 62301714, and 62301715), and one class is related to prosthetic devices for the knee (62302015). As we describe below, these classes are ones in which companies in the investigation historically relied heavily on physician co-inventions, and where such co-inventions reduced most dramatically following the DOJ investigation.

[Figure 3 HERE]

Table 6 reports the results of the regression analysis of changes in technology space based on the patent data, at the firm-class-year level. These results confirm the rate of invention falls with the DOJ investigation (column 1), and for companies involved in the lawsuit relative to other companies (column 3). The decrease in the number of patents for companies involved in the lawsuit during the investigation is approximately 20% (based on results in column 3). More importantly, these results demonstrate the technology classes that show the largest declines in the number of inventions are the classes in which the number of patents with a physician-inventor decreases the most (where decrease is calculated at the firm-class level). Recall that for the companies involved in the lawsuit, a one-standard-deviation change in the number of physician patents in a technology class is 6.41; results in Table 6 suggest the associated reduction in patenting in that class would be 4%.

[Table 6 HERE]

Analysis of the FDA-approved product data suggests the same pattern. The final column in Table 4 uses the number of FDA product classes in which a firm generated innovations in the year as the dependent variable, and demonstrates that companies involved in the lawsuit reduced the number of product areas in which they were actively innovating after the lawsuit, relative to other companies. To investigate the classes in which these companies were reducing innovation, we estimate the effect of the DOJ investigation on the number of innovations generated by companies in the lawsuit in the five categories of product classes described above. For the companies involved in the lawsuit, 50% of innovations were in Prosthesis, 27% were in Fixation devices, 16% were in Spine, 3% were in Bone materials, and less than 1% were in codes attributed to the Miscellaneous category. Results of the analysis of the number of innovations in each of these categories, reported in Table 7, suggest the most significant decrease in innovation during the DOJ period was in Prosthesis, Spine, and Bone materials, with no statistically significant reductions in Fixation devices or Surgical instruments.

[Table 7 HERE]

Mapping all of the FDA product class categories to corresponding patent technology classes is not feasible. Of these categories, Prosthesis and Spine, map to patent technology classes in the most straightforward way.[6] Companies in the lawsuit historically relied heavily on physician input in the technology classes associated with Prosthesis and Spine: the percentage of company patents with a physician-inventor was 17% in Prosthesis and 21% in Spine before the DOJ lawsuit, while it was 12% in other orthopedic classes. These classes also saw the most substantial reduction in patents with physician-inventors from pre- to post-lawsuit (from 17% to 8% in Prosthesis, from 21% to 9% in Spine, while other classes dropped only from 12% to 10%).

These analyses together suggest the disruption of the market for ideas brought about by the DOJ lawsuit did shape the direction of innovation. In particular, inventive outcomes shifted toward lower-quality inventions, and inventive and innovative outcomes shifted away from areas historically dependent on physician input, where the frictions in the market for ideas most significantly reduced physician input.

Discussion

In the last generation, scholars have made tremendous strides in estimating the impact of technological progress on economic growth (Mowery and Rosenberg 1991). More recent work has focused on how technological innovation is organized. In light of the significant hazards of buying and selling ideas (Arrow 1971), the market for ideas represents a crucial piece of infrastructure that facilitates the division

[6] USPTO technology class 623 contains Prosthesis and Spine devices, in subclasses easily identifiable from the subclass titles available on the USPTO website. In addition, several subclasses in classes 606 and 607 explicitly contain devices related to spine.

of innovative labor, gains from the trade, and the efficient utilization of technology. The market for ideas in turn supports firms' open-innovation strategies (Chesbrough 2003), where ideas flow across organizational boundaries.

Although an influential body of prior work has described clearly the market for ideas (Gans, Hsu, and Stern 2002; Gans and Stern 2003; Arora et al. 2004; Arora and Gambardella 2010), we still have sparse evidence on how crucial it is for the rate and direction of innovation, a central question in any consideration of welfare. To fill this gap in the literature, this paper exploits a series of frictions introduced to the market for ideas in the medical device industry as a result of a DOJ investigation in 2005. Previously, this market has facilitated widespread collaboration between physician-inventors and incumbent medical device firms. We find evidence that the investigation dramatically slowed the rate of innovation at the industry level and shifted the direction of innovation away from those areas in which physician-inventors had been especially important.

Our findings suggest the market for ideas has an important positive effect on the generation of new innovations, most likely through facilitating specialization and gains from trade. Moreover, the presence of a market for ideas allows innovation to progress in new directions, in our case, the important domains of spinal devices and prostheses, where physician knowledge is especially valuable. The notion that the market allows the production of devices that would not exist otherwise is key to understanding the impact on social welfare (c.f. Chamberlin 1950). However, estimating the effect on social welfare is not straightforward. Although product variety offers consumers more choices and could increase welfare, many medical devices and other health care products might be offering only incremental advances at a considerable premium. Thus, for example, fewer new spinal implants as a result of the investigation may have had minimal impact on social welfare. Future research could estimate the welfare implications of the DOJ investigation more systematically.

Ironically, one of the purposes of the DOJ investigation was to protect consumers by ensuring fair competition in the market between orthopedic device makers and physicians. Through curtailing conflicts of interest, regulators could have presumably leveled the playing field across competing devices and reduced barriers to entry. In practice, the presence of a robust market for ideas makes policy intervention more complex and fosters unintended consequences. Our results suggest that what could have been a pro-competitive intervention actually reduced the rate of new products introduced and shifted the direction toward lower-quality inventions in product categories in which firms were already active. The ultimate result may have been reduced competition in the product market.

Our finding on the declining rate of innovation at the aggregate level in orthopedics is especially notable, and not at all obvious without empirical corroboration. The firms under investigation continued to invest in R&D and could have theoretically made up for the gap created by frictions in the market for

ideas by generating more internal knowledge. Moreover, other firms not under investigation, including new entrants to the market, could have increased their innovative output enough to compensate for any decline by the firms under investigation. But our results demonstrate they did not do so. Although some physician-inventors shifted from working with the companies under investigation to other companies (as evidenced by the shift in patent assignment of physician inventions in orthopedics), this shift was not significant enough to maintain the growth rate in the aggregate level of innovation in the sector. Many physician-inventors were likely precluded from access to the downstream market, and other would-be inventors likely elected not to pursue inventions in response to these new frictions in the market. Further, the companies that did increase collaboration with physicians may have been inferior matches (in terms of complementary assets) relative to the companies under investigation. These factors could help to explain how a relatively small change in magnitude in terms of patent citations translated into a large decline in product innovation.

Despite these contributions, our study has some limitations. First, we examine frictions in only one part of the market for ideas: the interface between user-inventors and companies. Other avenues are certainly available for transactions, including between existing firms. Despite our narrow focus, we think this approach allows us to focus on an empirically identifiable change in the market. We find a significant decline and marked shift in direction in innovation precipitated by frictions in this one part of the market for ideas. These findings likely underestimate the true benefits that arise from the presence of the market for ideas more generally.

In sum, our results provide the first empirical evidence that the market for ideas has a significant impact on the rate and direction of innovation. Coupled with previous work on the characteristics of the market and how it shapes decisions, we can move closer to a more comprehensive explanation for how the organization of technology commercialization activities is related to the speed and nature of technological progress, and ultimately economic growth.

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Table 1: Description of Variables

Variable	Level of observation	Description	Source
DOJ	Daily in pa tent data, Annual in annual data	Equal to 1 during the DOJ investigation and settlement period (March 20, 2005-March 30, 2009), zero otherwise	Press releases
Ortho	Patent	Equal to 1 for patents w/ orthopedics technology classifications	Delphion patent database and USPTO Technology Profile report.
DrPat	Patent	Equal to 1 for patents with at lease one doctor inventor	Delphion patent database combined with AMA Physician masterfile
Company Assigned	Patent	Equal to 1 for patents assigned to companies (rather than individuals, governments, or unassigned).	Delphion patent database
Assigned to company under investigation (SuitCo)	Patent	Equal to 1 for patents assigned to the five companies involved in the DOJ lawsuit.	Delphion patent database
Assigned to company not under investigation	Patent	Equal to 1 for patents assigned to a company other than the five companies involved in the DOJ lawsuit.	Delphion patent database
Granted	Patent	Equal to 1 for patent applications that were granted as of the date of data download	Delphion patent database
# Patents	Firm-technology class-year	Count of the number of patents in the firm-technology-class year	Delphion patent database
ChngNumDr	Firm-technology class	# doctor co-invented patents in firm-class before DOJ less # doctor co-invented patents in firm-class post-DOJ; positive value is DECREASE in doctor patenting	Delphion patent database combined with AMA Physician masterfile
% Granted	Firm-technology class-year	Percentage of patents that were granted at the time of download	Delphion patent database
# Innovations	Firm-year	Count of FDA-approved products	U.S. FDA, Center for Devices and Radiological Health
# Product codes	Firm-year	Number of product codes in which the firm innovates	U.S. FDA, Center for Devices and Radiological Health

Table 2: Summary Statistics for Patented Medical Device Inventions and FDA-Approved Products in Orthopedics, 2000-2010

	Mean	Std Dev	Min	Max
A. Patent-level Measures (N=155,950)				
Company Assigned	0.606	0.489	0	1
Assigned to company not under investigation	0.586	0.492	0	1
Assigned to company under investigation	0.020	0.138	0	1
DrPat	0.138	0.345	0	1
DOJ	0.409	0.492	0	1
Ortho	0.111	0.314	0	1
DrPat X Ortho	0.022	0.146	0	1
DrPat X DOJ	0.056	0.230	0	1
Granted	0.402	0.490	0	1
B. Firm-Tech. class – Year Patent Measures (N=222,120)				
# Patents	0.290	3.712	0	280
# Citations Received	1.843	39.683	0	6210
ChngNumDr	0.106	2.027	-49	132
% Granted	0.021	0.130	0	1
C. Firm-year Product Innovation Measures (N=8,850)				
# Innovations	0.496	2.731	0	62
# Product Codes	0.334	1.450	0	28

Figure 1: FDA-approved orthopedic products: Suit companies, other companies, and total

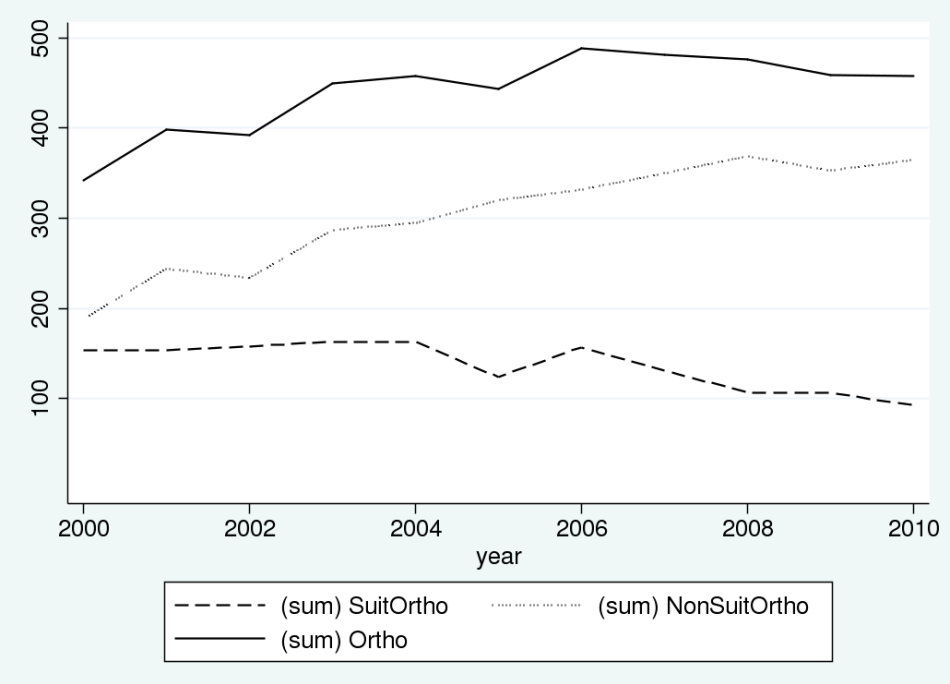


Table 3: Likelihood of Patent Assignment to Companies Before and After DOJ Investigation, 2000-2010

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Company Assigned=1	Company Assigned=1	Assigned to Company not under investigation=1	Assigned to Company not under investigation=1	Assigned to Company under investigation=1	Assigned to Company under investigation=1	Assigned to Company under investigation=1
DrPat	-0.155	-0.151	-0.134	-0.144	-0.116	-0.100	-0.101
	(0.013)**	(0.014)**	(0.013)**	(0.014)**	(0.032)**	(0.033)**	(0.033)**
DrPat X DOJ	-0.117	-0.132	-0.096	-0.131	-0.177	-0.193	-0.194
	(0.020)**	(0.022)**	(0.020)**	(0.022)**	(0.054)**	(0.055)**	(0.053)**
DOJ	0.069	0.069	0.061	0.055	0.079	0.109	0.108
	(0.019)**	(0.019)**	(0.019)**	(0.019)**	(0.049)	(0.064)	(0.064)
Granted	1.321	1.324	1.209	1.235	0.521	0.524	0.522
	(0.008)**	(0.008)**	(0.008)**	(0.008)**	(0.019)**	(0.019)**	(0.019)**
DrPatXOrtho		-0.021		0.109			
		(0.037)		(0.037)**			
DrPatXOrtho XDOJ		0.107		0.233			
		(0.057)		(0.057)**			
Ortho		-0.116		-0.571			
		(0.018)**		(0.018)**			
OrthoXDOJ		-0.009		0.023			
		(0.025)		(0.025)			
Constant	-0.626	-0.630	-0.538	-0.558	-3.510	-3.499	-3.512
	(0.020)**	(0.020)**	(0.019)**	(0.019)**	(0.090)**	(0.090)**	(0.090)**
Observations	155950	155950	155950	155950	152627	143194	152627

Robust standard errors in parentheses; * significant at 5%; ** significant at 1%
Probit regressions, all estimations include technology class and year indicator variables.
DV in (1) and (2) equal to 1 for patents assigned to companies; DV in (3) and (4) equal to 1 for patents assigned to companies not involved in the DOJ lawsuit; DV in (5)-(7) equal to 1 for patents assigned to the five companies involved in the DOJ lawsuit.
(6) demonstrates robustness to truncating the analysis at the end of the DOJ settlement period, March 30, 2009.
(7) demonstrates robustness to treating the post-settlement period (March 30, 2009 – end 2010) as part of the treatment period.
Number of observations varies because technology class fixed effects necessitates dropping observations from technology classes that perfectly predict failure (0) in the dependent variable.

Table 4: Annual # Innovations and # Product Codes in Orthopedics, Firm-Year count, 2000-2009

	(1)	(2)	(3)	(4)
	NumInnov	NumInnov	NumInnov	NumProdcodes
Suit Company	4.412			
	(0.198)**			
New Venture	0.152			
	(0.254)			
Suit Company X DOJ		-0.560	-0.563	-0.531
		(0.149)**	(0.162)**	(0.104)**
New Venture X DOJ			0.550	
			(0.260)*	
Constant	-1.055			
	(0.133)**			
Year FE	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes
Observations	8850	5170	5170	5170
# Firms		517	517	517

Robust standard errors in parentheses
* significant at 5% level; ** significant at 1% level
(1) is Poisson models.
(2)-(4) are Poisson Quasi-maximum likelihood with conditional fixed effects at the firm level.

Figure 2: Annual R&D Spending by Companies Involved in DOJ Investigation, 2003=1

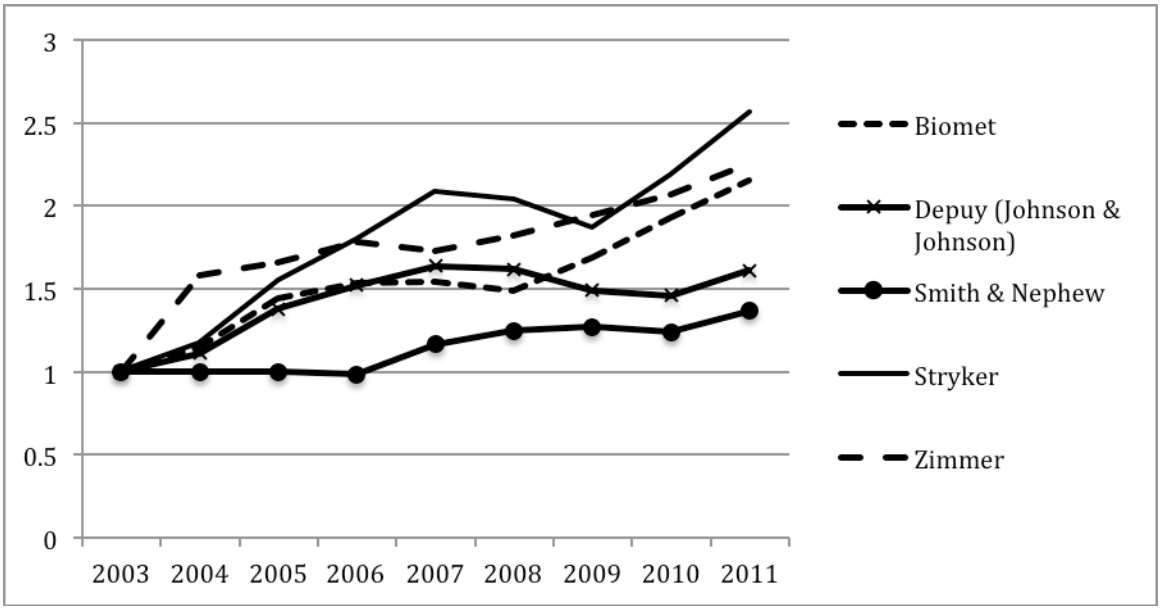


Table 5: Number of Forward Citations Received as a Function of Decreases in Doctor Co-Patenting, 2000-March 2009

	(1)	(2)	(3)	(4)	(5)
Suit CompanyXDOJ	-0.005	0.018	0.055	0.065	0.155
	(0.197)	(0.180)	(0.178)	(0.172)	(0.164)
ChngNumDrXDOJ		-0.013		-0.007	-0.007
		(0.003)**		(0.003)**	(0.002)**
# Patents in firm-class-year			0.016	0.015	0.014
			(0.004)**	(0.004)**	(0.003)**
% Granted patents					1.371
					(0.125)**
Year Fs	Yes	Yes	Yes	Yes	Yes
Firm-class FEs	Yes	Yes	Yes	Yes	Yes
Observations	30640	30640	30640	30640	30640
# Firm-classes	3064	3064	3064	3064	3064

Robust standard errors in parentheses

* significant at 5% level; ** significant at 1% level

Dependent variable is the total count of citations received by patents in the firm-class-year. Overall result is that in classes in which the firm reduces doctor co-patenting more, the "importance" or "quality" of the firms' patents fell the most post-DOJ.

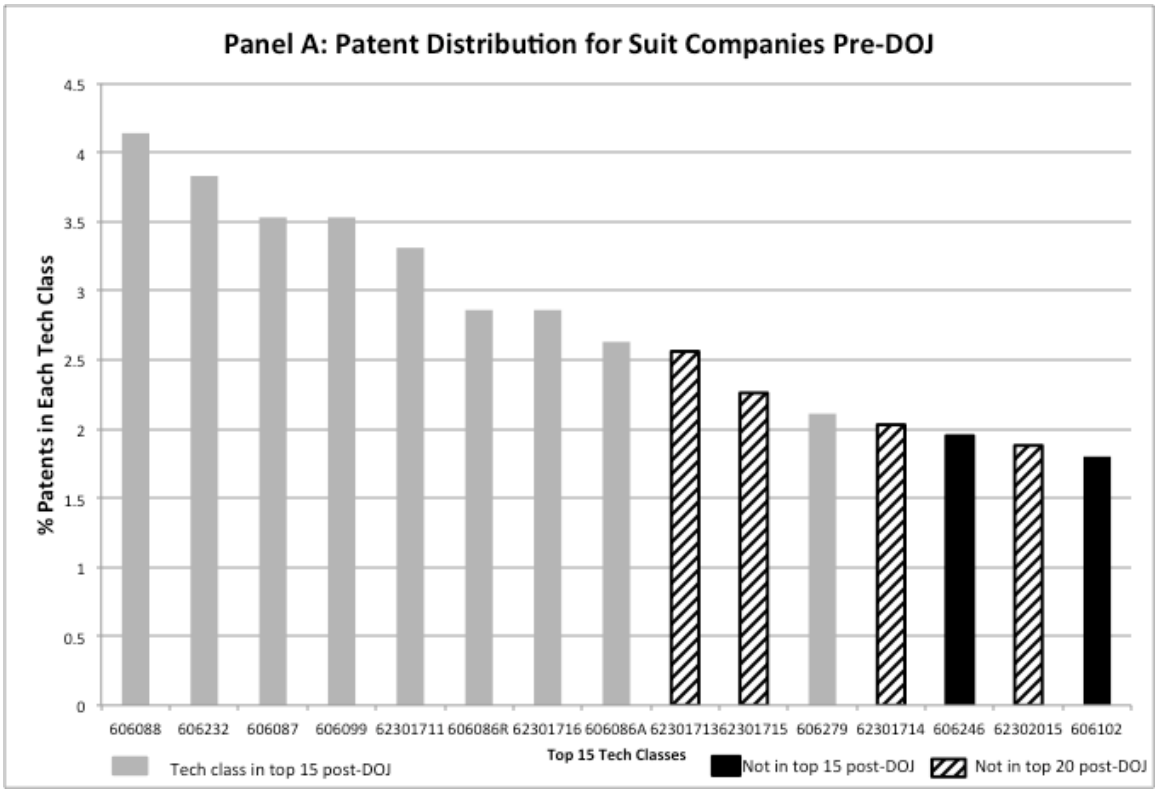
(3) and (4) also control for the number of patents in the firm-class-year, so the analysis reflects the average citations to patents in the firm-class-year.

(5) includes a control for the percentage of patents in the firm-class-year that are granted patents, rather than applications.

Note: ChngNumDr is the number of a firm's doctor-invented patents in a class prior to the DOJ investigation less the number of that firm's doctor-invented patents in that class after the investigation, so a positive value is a DECREASE in doctor patenting.

Note: This analysis is limited to the "standard" companies in the TI data, which represent 44% of the patents in the medical device classes, and excludes small companies, universities, and patents assigned to individuals or unassigned.

Figure 3: Distribution of Patents Across Technology Classes



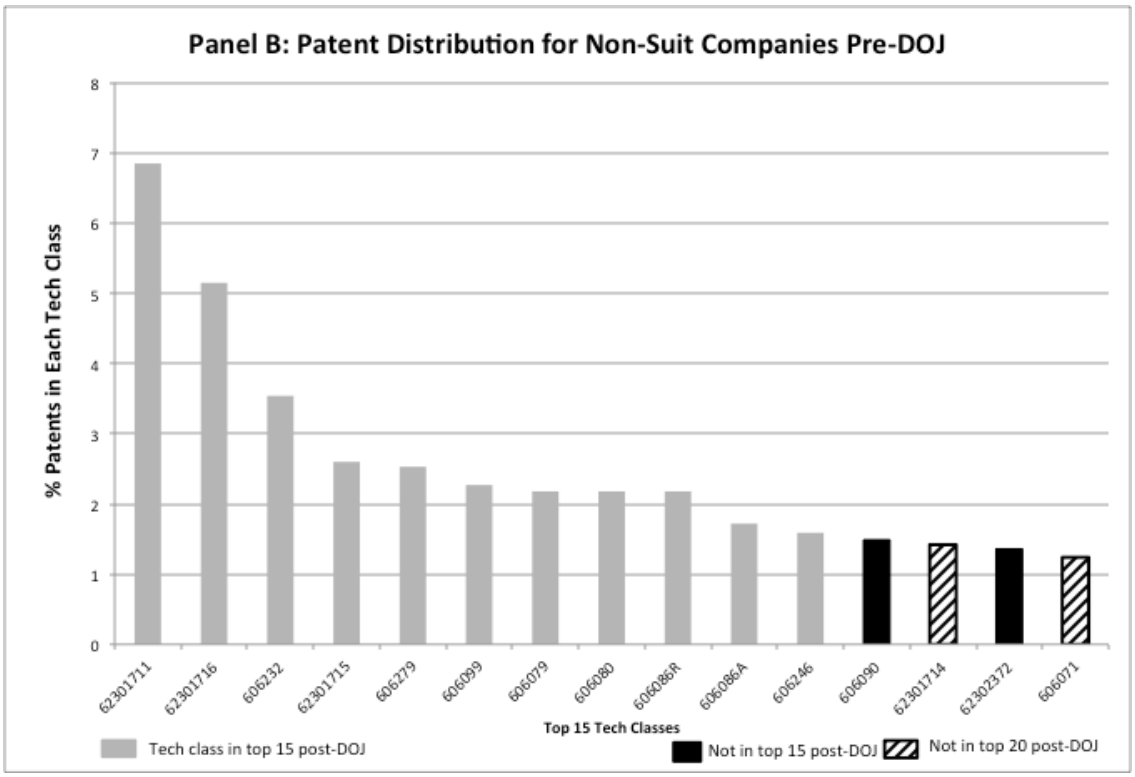


Table 6: Number of Patents by Firm-Class-Year for Large Companies, 2000-March 2009

	(1)	(2)	(3)	(4)
DOJ	-0.213			
	(0.033)**			
ChngNumDr X DOJ		-0.006		-0.006
		(0.002)**		(0.002)**
Suit Company X DOJ			-0.229	-0.201
			(0.081)**	(0.077)**
Firm-Class Fes	Yes	Yes	Yes	Yes
Year FEs	No	Yes	Yes	Yes
Observations	40480	40480	40480	40480
# Firm-classes	4048	4048	4048	4048

Robust standard errors in parentheses
* significant at 5% level; ** significant at 1% level
Note: ChngNumDr is the number of a firm's doctor-invented patents in a class prior to the DOJ investigation less the number of that firm's doctor-invented patents in that class after the investigation, so a positive value is a DECREASE in doctor patenting.
Note: This analysis is limited to the "standard" companies in the TI data, which represent 44% of the patents in the medical device classes, and excludes small companies, universities, and patents assigned to individuals or unassigned.

Table 7: Number of FDA-Approved Products by Category within Orthopedics, 2000-2009

	(1)	(2)	(3)	(4)	(5)
	Prosthesis	**Fixation**	**Surgical Instr.**	**Spine**	**Bone**
Suit Company X DOJ	-0.406	-0.380	0.039	-0.662	-0.895
	(0.186)*	(0.296)	(0.415)	(0.313)*	(0.236)**
Observations	940	2090	840	1590	1030
# Firms	94	209	84	159	103

Robust standard errors in parentheses
* significant at 5% level; ** significant at 1% level
Estimation is Poisson Quasi-maximum likelihood with conditional firm fixed effects and year fixed effects.