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Independent Boards and Innovation*

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Abstract

Much research has suggested that independent boards of directors are more effective in reducing agency costs and improving firm governance. Less clear, however, is how independent boards influence innovation and innovation search strategies. Relying on regulatory changes that required shareholders to appoint a majority of independent directors, we demonstrate how the transition to independent boards results in greater but less creative patenting. We argue that the greater oversight of independent boards results in greater managerial effort, less tolerance of failure and hence managerial risk aversion, greater constraint on strategic flexibility, and pressure for immediate and quantifiable results. As a result, managers increase patenting by exploiting extant capabilities and technologies, at the expense of searching for new technologies. We demonstrate that firms that transition to independent boards are less likely to explore uncrowded and unfamiliar technologies. Such firms patent more and get more total citations to their patents, though the increase comes mainly from patents in the middle of the citation distribution; the numbers of uncited and highly cited patents - arguably corresponding to completely failed and breakthrough inventions, respectively - do not change significantly.

Keywords: Corporate Governance, Innovation, Patents, Board Composition, Independent Directors

JEL Classification: G34, L14, L25, M21

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1 Introduction

The board of directors has an important role in the governance of corporations. Charged with overseeing and advising managers, it can effectively reduce agency costs that arise from the separation of ownership and control.

Several authors have argued that independent directors, with no ties to the company other than their directorship, are better suited to perform this role as they can credibly limit managerial discretion by punishing managers after undesirable outcomes. Independent boards are thus more likely to produce decisions that are consistent with shareholder-wealth maximization (e.g. Fama and Jensen, 1983; Williamson, 1983).

Such limited managerial discretion, however, may have unintended effects on corporate innovation. A manager with limited discretion may be reluctant to engage in exploratory projects, since the value of those projects depend on the flexibility to adapt after observing outcomes (Manso, Balsmeier, and Fleming, 2015). Moreover, the fear of being punished (or dismissed) after poor performance could induce the managers to play it safe and avoid exploratory strategies (Manso, 2011).

We investigate the effect of board independence on search and innovation processes. Consistent with many classical models, we propose for our first hypothesis that patent counts grow as boards become more independent. Independent boards are more likely to terminate the manager in case of poor performance (Weisbach, 1988) and this threat provides an incentive to the manager to work hard (Sitglitz and Weiss, 1983). Increased monitoring from independent boards may alleviate agency problems such as shirking or tunneling of corporate resources. Managers should also take actions that are - and appear to be - closer to the interests of shareholders (Harris and Raviv, 1978; Holmstrom, 1979; Holmstrom and Milgrom, 1991). When under increased scrutiny and demands for results, managers will focus on quantifiable results - such as a greater number of patents. They will adduce an increase in patent count to satisfy demands for performance.

On the other hand, by punishing managers after failure and limiting managerial discretion, board independence may also stifle innovation. Our second and more subtle hypothesis is that as boards become more independent, patents filed by the firm will become less novel and less creative. Greater oversight will increase managerial focus upon immediate commercial gain; rather than embark on risky exploration of new technologies, managers will focus on harvesting currently successful approaches. Because they are more likely to get fired for poor performance, and are under pressure for immediate results, managers become more risk adverse and will invest less in potentially lengthy and fruitless searches for truly novel solutions. This occurs despite the possibility that exploration could increase the chance for a breakthrough, because it could also increase the chance for complete failure (the probability distribution flattens as failures and breakthroughs both become more likely). Even if it occurs, a breakthrough becomes less attractive to a manager, because an independent board is less likely to agree upon its subsequent commercialization strategy. Hence, a manager is less likely to search for that breakthrough in the first place. Rather than explain why they are moving the firm into an area in which it - and possibly no firm - has experience, managers will stick to proven competencies that the board and the market can understand. All these mechanisms cause a manager to exploit in order to maximize the mean outcome, rather than explore and increase the variance that can lead to a breakthrough (March 1991).

These behaviors cohere with a number of theoretical models. Because board independence limits managerial discretion, it can affect the type of projects managers choose to engage on (Manso, Balsmeier, Fleming 2015); the loss of flexibility produced by independent boards induces the manager to choose less exploratory projects, because they require less adaptability. Independent boards are more likely to fire a manager after poor performance. As argued by Manso (2011), this lack of job security induces managers to pursue less exploratory projects. Managers will avoid new technologies that may be construed as empire building (Jensen, 1986). Boards may also directly resist exploration of new areas, if they fear that in the short-term the stock market fails to recognize investments in innovation (Stein, 1989). Due to potential conflict of interests between independent board members and the manager, or alternately, less familiarity with the firm's industry and technology, the quality of research advice given by friendly boards may be higher than by independent boards (Adams and Ferreira 2007).

These arguments provide observable implications. Firms whose boards become independent will patent more but less novel technology. The patents will be in areas the firm has previously patented in. The patents will not be in new areas that other firms also avoid. Citations to the firm's patents will increase, though this increase will not result from investments in risky technologies that might provide a breakthrough or fail completely; instead, the citation increase will be generated by patents in the middle of the citation distribution. Furthermore, this increase in citations will be mediated by the movement of the firm into better known and more crowded areas of technical search; in other words, the firms' patents will be more highly cited simply as an artifact of their search strategy. Rather than start new technological trajectories, managers will direct their efforts towards maximizing the return on currently fertile trajectories. They will increase the first moment of innovative outcomes at the expense of the second.

Evidence comes from observing search strategies for firms that were forced by regulatory changes to adopt more independent boards. Starting in 1999, stock exchanges and the Sarbanes-Oxley Act (SOX) required firms to have a majority of independent directors (for similar approaches, see Linck et al. 2009; Duchin et al. 2010). Comparing firms that changed from less to more independent boards against firms that already had independent boards, we find increased patent output - but less creative and explorative patenting. Firms whose boards become more independent patent more and receive more citations to their patents, however, the effects are insignificant for uncited and highly cited patents. Firms whose boards become more independent also work in more crowded and more familiar technologies; the rates of prior and self citation increase. The evidence supports arguments for a more nuanced relationship between oversight and innovation; greater oversight appears to lead to greater effort and output, at the expense of innovative exploration and search.

2 Literature review

A large literature studies the role and influence of board characteristics (for an overview see Adams, Hermalin, and Weisbach, 2010; for the economic relevance of boards see Ahern and Dittmar, 2012). Much of the literature focuses on the role of independent board members (most recently e.g. Masulis and Mobbs, 2014; Brochet and Srinivasan, 2014). Several studies have analyzed how independent directors influence CEO compensation (e.g. Faleye, Hoitash, and Hoitash 2011; Coles, Daniel, and Naveen, 2008; Denis and Sarin, 1999; Core, Holthausen and Larcker, 1999), CEO appointments and dismissals (Knyazeva, Knyazeva, and Masulis, 2013; Guo and Masulis, 2011; Borokhovich, Parrino, and Trapani, 1996; Weisbach, 1988), adoption of antitakeover defenses (Brickley, Coles, and Terry, 1994) or takeover premiums (Cotter, Shivdasani, and Zenner, 1997; Byrd and Hickman, 1992). From these studies the picture emerges that independent board members increase board oversight. Whether such intensified board monitoring is beneficial or detrimental to shareholder wealth is less clear and may depend on the complexity of a firm's operations (Faleye, Hoitash, and Hoitash, 2011; Duchin, Matsusaka, and Oguzhan, 2010; Nguyen and Nielsen, 2010).

Several recent papers empirically study how corporate governance affects innovation, looking at determinants such as managerial compensation (Ederer and Manso, 2013; Baranchuk, Kieschnick, and Moussawi, 2014), firm's going public decision (Bernstein, 2012), private equity/venture capital involvement (Lerner, Sorensen, and Stromberg, 2011; Tian and Wang, 2014; Chemmanur, Loutskina, and Tian, 2014), anti-takeover provisions (Atanassov, 2013; Chemmanur and Tian, 2014), institutional ownership (Aghion, Van Reenen, and Zingales, 2013), financial market development (Hsu, Tian, and Xu, 2014), conglomerate structure (Seru, 2014), analyst coverage (He and Tian, 2013), and stock market liquidity (Fang, Tian, and Tice, 2013).

Almost all of this literature uses patent data to test their models.[1] Raw patent counts

[1] See Lerner and Seru (2014) for a criticism of the abuse of patent data.

are usually supplemented by the number of citations that a patent receives, as this measure correlates with financial and technical value (Harhoff 1999; Hall et al., 2005). Though less common, measures of originality and generality (Hall, Jaffe, and Trajtenberg 2001) have been used to measure breadth and impact of innovations, (see Lerner, Sorensen, and Stromberg, 2011 and Hsu, Tian, and Xu, 2014).

Most similar to the current study, Faleye, Hoitash, and Hoitash (2011) find that monitoring intensity, as proxied by independent director presence on boards and committees, correlates negatively with citation weighted patent counts. Kang et al. (2014) find a positive correlation between social connections and assumedly "friendly" boards on the same measure. Balsmeier, Buchwald, and Stiebale (2014) show increased patenting by firms whose boards are composed of executives from more innovative firms. The current study goes beyond these studies using more nuanced innovation measures and investigating the full distribution of citations.

3 Identification strategy

Identification for our study relies upon regulatory changes that forced public firms to increase the presence of independent directors on their boards in the early 2000s. The effects of those regulatory changes on variables other than innovation have been analyzed elsewhere (see e.g. Linck et al. 2009; and Duchin et al., 2010, for a setup that is most similar to ours). In this section, we briefly describe the regulatory framework that is relevant to our analysis.

Initiated by recommendations of the Blue Ribbon Committee (BRC) in 1999, stock market rules of the NYSE and Nasdaq have been built upon the assumption that independent board members are better able to monitor managers. Subsequent to the BRC recommendations, the Securities and Exchange Commission (SEC) approved new rules in December 1999, requiring public firms to move to a fully independent audit committee with the next re-election or replacement of audit committee members. Further motivated by prominent corporate scandals, e.g. Enron, this rule was written into U.S. law in 2002 as a part of the Sarbanes-Oxley Act (SOX). It was followed by subsequent NYSE and Nasdaq regulations in 2003 that imposed even stricter requirements on board composition. In addition to having an audit committee composed of merely independent directors, both stock exchanges forced firms to have a majority of independent directors as regular board members, and the compensation and nomination committees had to consist of 100% independent board members (>50% if firms are listed on Nasdaq only).

Definitions of director independence vary slightly across each rule. SOX states in section 301 that a given director is independent if the person does not “accept any consulting, advisory, or other compensatory fee from the issuer” (except for serving the board), and is not an "affiliated person of the issuer or any subsidiary" (NYSE speaks of "no material relationship"; and Nasdaq requires no relationship that would interfere with "independent judgment"). The NYSE and Nasdaq regulations are clear; the independence assumption is violated, for instance, if a director him- or herself or a direct family member was an employee of the firm during the previous three years, or a family member works for a third firm with which the given firm has a professional relationship, or a family member is connected to the firm's auditor.

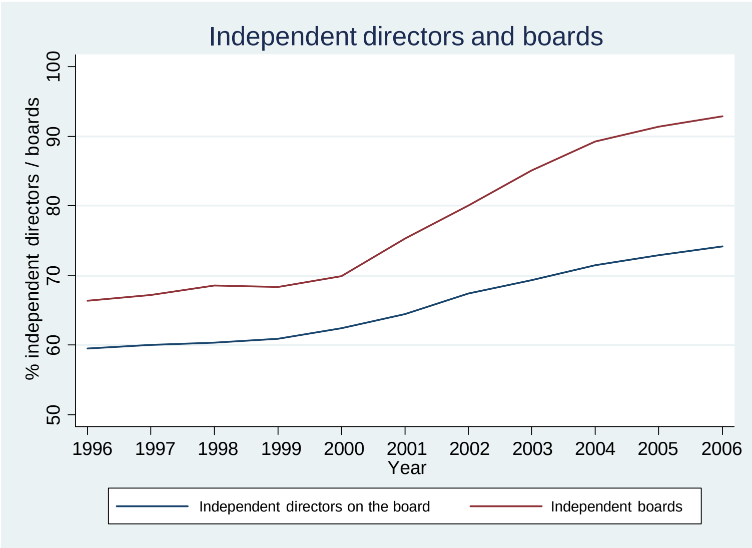
These regulations made board changes necessary for a large group of firms. The number and fraction of independent board members was fairly stable until the year 2000. As the described board regulations came into effect, more and more independent directors were appointed to corporate boards. Figure 1 illustrates the changes in board composition for the sample of firms used in our study. It resembles a pattern that has been documented in other studies for differing sets of public firms (e.g. Linck et al., 2008, and Duchin et al., 2010). Board composition data are taken from the Investor Responsibility Research Center (IRRC). From 1996 to 2006 the IRRC tracked individual board members of all major public U.S. firms and indicated in their database whether an individual board member is independent, an employee of the firm or otherwise affiliated (former employee, employee of an organization that receives charitable gifts from the company, employee of a customer or supplier to the company, relative of an executive director, etc.).

Reflecting the previously introduced regulatory changes, Figure 1 shows an increase of independent director presence on corporate boards from 2001 to 2006. Theoretical considerations about board control suggest that a crucial difference arises when a board switches from a minority to a majority of independent board members (Harris and Raviv, 2008).[2] It was further an explicit requirement of regulatory reforms. Thus, our analysis focuses on this variable. Our data also show that the proportion of firms with a majority of independent board members stayed rather stable around 68% before 2000 and moved up to about 94% by 2006.

Our empirical identification of the relationship between board independence and innovation stems from the difference between firms who were already in compliance with the regulatory changes before 2001 and those firms who switch to a majority of independent directors after regulatory changes became effective. Hence, all firms that

[2] The fraction of independent board members provides more variation but has two major disadvantages. First, considering board voting behavior, it is likely that the influence of independent directors on board oversight does not linearly increase with the number or fraction of independent members but exhibits a jump when independent directors gain or lose the majority of votes. Second, the switch from a minority to a majority of independent directors was an explicit requirement of regulation, such that it is much more likely that observed changes in that regard happened involuntarily, which in turn improves the identification of causal effects.

Figure 1: Fractions of independent boards and directors



Notes: This graph illustrates the evolution of independent boards over the sampling period. A board is defined as independent in the empirical estimations if the majority of board members are classified as independent by the Investor Responsibility Research Center (IRRC). In this graph, independent directors represents the average fraction of independent board members of all firms in the study.

were not required to change their board serve as a control group. In line with Duchin et al. (2010), we define firms as treated when they switch to an independent board after 2000 and have an audit committee that contains 100% independent board members. The latter requirement helps to sort out potential voluntary switches, increasing the amount of truly exogenous increases of independent board members and making our main variable of interest less likely to be confounded by endogenous choice. The fraction of independent directors increased by 25% during 2001 to 2006 within noncompliant firms and by 9% within firms that had already fulfilled the regulatory requirements before 2000.

4 Sample selection

The dataset we built up for our study is determined by the joint availability of data on the composition of corporate boards and committees from the IRRC, information on basic firm characteristics from Compustat, and patent data from the NBER, the Fung Institute and the USPTO. The IRRC provides data on corporate board members for 3000 major public U.S. based firms from 1996 to 2006. Compustat has further information on almost all of the firms covered by IRRC. A major challenge for the empirical researcher interested in those firms' innovative activities is the identification and compilation of the corresponding patent portfolios. Researchers involved in the NBER patent data project have spent significant amounts of resources to identify patents that have been granted to U.S. based firms. The NBER patent database contains, however, only those patents that have been granted through 2006. Due to the time lag with which inventions are granted property rights (1-5 years) and the publication of corresponding data by the USPTO, this results in significantly truncated data for patents filed after 2001. Researchers have found ways to use incomplete patent data for the years 2002 to 2006, exploiting the distribution of applications before 2002, but those approaches add noise to econometric analyses, and lead to significant estimation errors in our case, because our sample of board data covers 50% of years for which the NBER data is severely truncated. The issue becomes even more prevalent if researchers want to take citations to patents into account that often occur several years after a patent has been granted. In terms of patent applications, the NBER data misses 18 percent of patent applications of U.S. based assignees identified in 2002, rising to 99 percent by 2006.[3]

Newly available disambiguations (see Fiero et al., 2014) provide more recent data, avoid the truncation of the NBER patent database, and identify comprehensive patent

[3]The numbers are derived by comparing all patent applications in the NBER database with all patents in the Fung Institutes database as published in April 2014.

portfolios of the firms in our sample up to the year 2007.[4] Following the literature (e.g. He and Tian 2013), we assign an eventually granted patent to the year it was applied for. Disambiguation of firm names presents a major challenge, since patent documents do not contain a unique identifier of assignees. Following disambiguation, patents are aggregated to the firm level and merged with other databases such Compustat and IRRC.

We extended the reach of the NBER patent database by combining it with USPTO and Fung Institute data, including patent citations and other detailed information within each patent document. We started with standardized assignee names provided by the USPTO for all patents granted through December 31, 2012. These standardized assignee names are largely free of misspellings but still contain many name abbreviations for individual firms. The standardized USPTO assignee names remain consistent throughout time and have been used by the NBER patent project team to disambiguate firm names. For almost all US firms that received at least one patent between 1975 and 2006, the NBER provides a unique time invariant assignee. We took all variations of standardized assignee names that belong to a given single firm as a training set, and gave all granted patents that appear with the same standardized assignee name the same unique NBER identifier.[5] These information enabled us to track firms' patenting activity over significantly longer time periods, overcoming truncation issues of patent applications and generally increasing the accuracy of available patent portfolios.

Finally, we merged unique time invariant Compustat identifiers to the patent assignee identifiers as they are provided by the NBER. It is worthwhile to note that in our analysis we take only those firms into account for which the NBER has identified Compustat matches, and we assigned zero patents only to those firms where the NBER team searched for but could not find matches with any patent. In this regard we deviate from other studies that assign zero patents also to those firms that have not been tested to appear as a patent assignee or not. Thus, we avoid measurement errors at the expense of a smaller but more accurate dataset.

In order to circumvent potential selection effects to confound our estimation of the relationship between board independence and innovation, we further removed all firms that appear only before the year 2000 or entered the sample in the year 2000 or later, such that the remaining firms can be observed over a timespan where the previously described regulatory changes took place. Finally, we arrive at a sample of 6107 observations on 799 firms observed during the period from 1996 to 2006 for which we

[4]We gather patent data through 2007, because we will estimate regressions of firms' patenting activities in year t on board data and controls in t-1, reflecting that patenting activities need some time to be influenced by boards and simultaneous determination of variables may otherwise confound the estimation.

[5]Based on the first assignee that appears on the patent document. It allowed us to identify ~250k additional patents granted to U.S. based assignees after 2006.

could gather all information of interest. All firms in the sample combined have applied for 328,463 patents during the sample period.

4.1 Measuring innovative search

Much recent empirical work on corporate governance and innovation has relied on patent data (e.g. Atanassov, 2013; He and Tian, 2013). Raw patent counts are used as well as the number of future prior art citations that a patent receives, as the number of future cites correlates with financial and technical value (Harhoff 1999; Hall et al., 2005). Measures of originality and generality (Hall, Jaffe, and Trajtenberg 2001) are occasionally used to measure breadth and impact of innovations (see Lerner, Sorensen, and Stromberg, 2011 and Hsu, Tian, and Xu, 2014).

To be comparable with the extant literature we will show how board independence influences patent counts and citations. Raw patent counts and citations are, however, of limited use to identify differences in innovative search strategies, specifically towards more or less exploration. Therefore, we introduce new measures. Those patent metrics serve as additional dependent variables beside raw patent counts and citations, enabling a richer picture of how board independence affects not only the rate but also the direction of innovation.

First, we calculate the number of citations that each patent makes to other patents. An increase in the number of backward citations reflects direct relations to more prior art that must be specified in the patent application (required by law). This correlates with innovative search in relatively more crowded, better-known, and more mature technological areas.

Second, we take the number of times a given patent cites other patents owned by the same company. More self-cites indicate search within previously known areas of expertise while fewer self-citations indicate a broadening of innovative search or efforts to explore areas that are new to the firm (Sorenson and Stuart, 2000).

Third, supplementing the analysis of differences in backward citations, we calculate the number of patents that are filed in technology classes previously unknown to the firm. Unknown patent classes are defined as those in which a given firm has not applied for any patent beforehand (starting in 1976). The complement is the number of patents applied for in known classes. A continuous measure of whether firms stay or deviate from known research areas is the technological proximity between the patents filed in year t and the existing patent portfolio held by the same firm up to year t-1 (Jaffe 1989):

$$P_{it} = \sum_{k=1}^{K} f_{ikt} f_{ikt_{-1}} \Big/ \left(\sum_{k=1}^{K} f_{ikt}^2 \cdot \sum_{k=1}^{K} f_{ikt_{-1}}^2 \right)^{\frac{1}{2}}$$

where f_{ikt} is the fraction of firm *i*'s patents that belong to patent class *k* at time *t*, and $f_{ikt_{-1}}$ is the fraction of firm *i*'s patent portfolio up to *t*-1 that belongs to patent class *k*. P_{it} ranges between 0 and 1. The highest possible value indicates that the patents filed in year *t* are distributed across patent classes in the exact same way as the portfolio of all patents of the same firm up to the previous year.[6] Positive coefficients in a regression would thus indicate a more narrow innovation trajectory within known areas.

Finally, following Azoulay, Graff Zivin and Manso (2011) we categorize patents according to how many citations they have received relative to other patents that have been applied for in the same technology class and year. We count a patent as a top 1% (10%) patent if the patent falls into the highest percentile (centile) of the citation distribution in the same technology class and application year. Further, we separately count all patents that received no citation at all and those that have received at least one citation but do not fall in the top 10% category.

4.2 Control variables

Following the extant literature, we control for a vector of firm characteristics that could confound the relation between board independence and a firm's innovative search and success. We compute all variables for firm *i* over its fiscal year *t*. *Board size* measures the number of board members as we want to insulate the effect of board independence from contemporary changes in the number of directors. Further, we found that the firms in our sample differ significantly in terms of *R&D* spending over total assets and firm size as measured by total assets - two variables that are naturally positively related to firms' innovation activities. In order to reduce the skewness in total assets we take the logarithm of total assets in all multivariate econometric analyses. In addition, we control for firm age (the number of years since the initial public offering date), as older firms may search in older technological areas. Moreover, *leverage* (long term debt over total assets) and *capital expenditures* (scaled by total assets) account for financial constraints that are known to influence corporate innovation. Finally, *Tobin's Q* enters the regression to control for differences in growth opportunities.

4.3 Summary statistics

Table 1 presents summary statistics on the dataset. The patenting activities of the firms in our sample show typical skewness with a mean of ~54 patents and a median of 3 patents. Related measures like the amount of R&D investment and citation-weighted patent counts reveal similar distributions and high concentrations among the most ac-

[6] Reflecting that a value of one indicates no change, the measure takes value one if no patent was applied for in a given year. All results presented below are robust to excluding non-patenting firms.

tive firms. We calculated the number of patents that cite a given patent based on all US granted patents by April 2014. To control for secular trends in citation rates we employ time fixed effects that presumably affect all firms equally on average (see also Atanassov, 2013; and Hall, Jaffe, and Trajtenberg, 2001). 680 firms (85%) have applied for at least one patent during the sampling period. The average firm has filed 0.5 (5.0 patents) in the top 1% (10%) category, 18.1 patents that are never cited and 30.6 that appear in the middle of the citation distribution. Similar to the number of cites received in the future, the number of backward citations is quite large on average with 1157.2 cites (median 26). On average, 176.6 of those backward citations relate to patents that belong to the same firm (median 0). Further, 1.3 patents are filed in new to the firm technology classes, while 52.5 are filed in known classes. The average technological proximity measure is 0.53.

Regarding other variables of interest, the average firm in our sample shows the following characteristics: it is 17.8 years old, has 9 board members, a book value of assets of $7 billion, a R&D to assets ratio of 4.8%, a leverage ratio of 18.2%, capital expenditures over total assets of 5.3%, and a Tobinś Q of 1.2.

4.4 Methodological remarks

In order to analyze how a switch to an independent board affects innovative search and success we follow the literature on corporate governance and innovation (e.g. Atanassov, 2013; He and Tian, 2013; Kortum and Lerner, 2000) and estimate the baseline model in OLS:

$$log(1 + patents_{i,t+1}) = \beta_0 + \beta_1 \cdot independentboard_{it} \cdot post_t + \gamma \cdot Z_{it} + \theta_t + \alpha_i + <_{it}$$

where $patents_{i,t+1}$ is the number of eventually granted patents of firm i applied for in year $t+1$. In alternative regressions we will exchange the number of patents with our previously introduced measures of innovation that allow us to assess the firms' innovative search and success in more detail.[7] Our main explanatory variable of interest is a dummy that indicates whether a given firm has switched from a minority to a majority of independent board members in the year 2001 or later when regulatory changes became effective. Under the assumption that changes in patenting by firms that switched to a majority of independent board members would have been comparable to changes in patenting by other firms in the absence of a switch to an independent board, β_1 cap-

[7] In case the dependent variable is a count, all results are robust to alternatively estimating Poisson regressions (not shown).

Table 1: Summary statistics

Variable	**N**	**mean**	**median**	**sd**	**min**	**max**
Patents	6107	53.78	3	243.36	0	5261
Citations	6107	573.70	5	3329.21	0	108496
Top 1%	6107	0.53	0	2.42	0	44
Top 10%	6107	5.06	0	25.18	0	660
Cited patents	6107	30.62	1	149.93	0	3512
Uncited patents	6107	18.13	1	98.77	0	4033
Back-citations	6107	1157.22	26	4851.25	0	101943
Self-citations	6107	176.60	0	990.85	0	22415
New classes	6107	1.28	0	3.88	0	227
Old classes	6107	52.50	2	242.47	0	5259
Tech. prox.	6107	0.54	0.68	0.41	0	1
Indep. Board	6107	0.77	1	0.42	0	1
Board size	6107	9.23	9	2.52	3	21
log(total assets)	6107	7.41	7.22	1.51	3.09	13.53
R&D /assets	6107	0.05	0.02	0.07	0	1.12
Age	6107	17.78	15	10.98	1	37
Cap. exp. /assets	6107	0.05	0.04	0.04	0	0.43
Leverage	6107	0.18	0.17	0.16	0	1.35
log(Q)	6107	1.23	1.04	0.85	-2.46	6.72

Notes: This table reports summary statistics of all variables used in the study. Board size is the number of board members. Independent board is an indicator variable that indicates whether the majority of board members are independent. Top (1%/10%) are patents that fall into the 1%/10% most cited patents within a given 3-digit class and application year. Cited patents are the no. of patents that received at least one citation but not enough to be in the top 10%. Uncited are the number of patents that were not cited. Self-citations are the number of cites to patents held by the same firm. Patents in new/old classes is the number of patents that are filed in classes where the given firm has filed no/at least one other patent beforehand. Technological proximity is the technological proximity between the patents filed in year *t* to the existing patent portfolio held by the same firm up to year *t*-1, and is calculated according to Jaffe (1989). Further information on variable definitions and data sources are provided in section 4.2.

tures the effect of board independence on innovation by the affected firms.[8] Z_{it} is a vector of the previously introduced firm characteristics, and year fixed effects θ_t control for changes in the macroeconomic environment and systematic changes in patenting activities over time. Our preferred specifications include firm fixed effects α_i that control for any unobserved firm heterogeneity that is time invariant. Hence, we basically estimate a DiD model, where those firms that switch form a minority to a majority of independent directors on the board after 2000 are the 'treated firms', and all others are 'non-treated firms'. In order to unravel the influence of firm fixed effects in our regressions we also show alternative models with industry fixed effects, based on 3-digit SIC industry dummies, instead of firm fixed effects. To stay within the DiD framework, we include a dummy variable that marks all treated firms in those regressions without firm fixed effects.

Identification hinges in all models upon the parallel trend assumption, stating that treated and non-treated firms show similar trends in the dependent variable of interest in the absence of treatment. In order to support the satisfaction of this assumption, below we present estimates of the dynamics of the treatment effect, evidence that the DiD estimator is not significantly different from zero in the absence of treatment.

Our estimation might still be biased, however, if other remaining cross-sectional heterogeneity of the firms in our sample change systematically with the change to an independent board and our measures of innovative search. In order to minimize concerns in this regard, we further re-estimate all our models based on a balanced sample, where treated and non-treated firms are comparable in terms of key observable characteristics before 2002. To achieve a balanced sample we use 'Coarsened Exact Matching' (CEM) (Blackwell et al., 2009).[9] CEM has several features that bound the degree of model dependence, reduce causal estimation error, bias, and inefficiency (Iacus, King, and Porro, 2009a, 2009b, 2011, for a similar application, see Azoulay, Zivin, and Wang 2010). Based on CEM's coarsening function we match treated and non-treated firms on the joint distribution of firms' R&D spending over total assets, firm size as measured by

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[8] As can be seen in Figure 2, not all firms switched from a friendly to an independent board at the same time, because directors were allowed to fulfill their contracts that were signed before the law change. In principle, this gives firms room for strategic choice that could confound our identification. Therefore, we checked whether the time between the law change and compliance is correlated with pre-SOX innovative activity of the firms in our sample. In order to test this, we first defined a variable that measures the years until the board actually changed from friendly to independent although SOX and other regulations were already active (2003). We found 17 firms with a one year lag, 14 with a two year lag and 8 with a three year lag. Then, we regressed time lag until compliance on firms' average amount of R&D, patents and cites before 2001 (results are robust to taking 2000 or 2002 instead). The lack of significant correlation between compliance lags and pre-treatment innovative activity increases confidence that the estimation is not biased by systematic choice of more or less innovative firms to switch later or earlier.

[9] In alternative models we balanced the sample based on propensity score matching, taking only the nearest neighbor of each treated firm as a control, and find qualitatively the same results.

the natural logarithm of total assets, the natural logarithm of Tobin's Q, boardsize and 26 two-digit SIC industry code dummies. We took the average values of those variables over the years 2000 and 2001 as matching criteria to ensure highest comparability before treatment.[10] Table 2 presents the differences in mean values of all control variables before and after the matching procedure.

Panel A and B of Table 2 show that treated firms in the full sample are on average a little smaller, invest less in R&D and have a smaller board. Except with regard to R&D spending, the relative differences of the two firm groups appear small in magnitude. Both firm groups are not statistically significant with regard to the mean values of the other control variables that have not explicitly been included in the matching. In order to eliminate any statistically significant differences of observable firm characteristics, while keeping as many treated firms as possible in the sample, we ran CEM with the side condition to differentiate firms according to ten categories of R&D spending and three categories of firm size, board size and Tobin's Q. Based on this procedure, for 4 out of the 125 treated firms we could not find any proper match. For the remaining 121 treated firms, CEM selected 430 comparable firms, i.e. 158 incomparable firms are subsequently discarded from the analysis. Panel B of Table 2 shows that, after matching, there are no statistically significant differences between the treated and non-treated firms according to two sided t-tests. Although not necessary for a consistent DiD estimation, it is worthwhile to mention that both firm groups do not differ in terms of the average amount of applied patents after matching.

While balancing the sample should improve identification (at least for firms that are similar to the treated firms), potential remaining differences in innovation trends might still have an influence on the estimation. Therefore, we also estimate models that allow for separate firm specific linear trends in innovation before 2002, using the following specification:

$$
\begin{aligned}
log(1 + patents_{i,t+1}) = \beta_0 + \beta_1 \cdot independent\ board_{it} \cdot post_t + \gamma \cdot Z_{it} \\
+ \delta \cdot firm_i \cdot pre2002_t \cdot t + \theta_t + \alpha_i + <_{it}
\end{aligned}
$$

where $pre2002_t$ equals one if the year of observation is 2001 or earlier.

Finally, in alternative specifications we further control for potential systematic changes in the influence of our controls on innovation after 2001, which may coincide with

[10]The results are robust to taking all available observations before 2001 into account.

Table 2: CEM matching of treated and non-treated firms

Variable	**no. of firms**	**mean**
Panel A: Treated firms before matching		
log(total assets)	125	7.02
R&D /assets	125	0.04
Age	125	2.45
Leverage	125	0.18
Cap. exp.	125	0.06
log(Q)	125	1.34
Board size	125	8.45
Panel B: Non-treated firms before matching		
log(total assets)	588	7.33**
R&D /assets	588	0.05*
Age	588	2.43
Leverage	588	0.20
Cap. exp.	588	0.05
log(Q)	588	1.25
Board size	588	8.99**
Panel C: Non-treated firms after matching		
log(total assets)	430	6.99
R&D /assets	430	0.04
Age	430	2.37
Leverage	430	0.20
Cap. exp.	430	0.05
log(Q)	430	1.21
Board size	430	8.56

Notes: This table reports mean values of treated and non-treated observable firm characteristics, averaged over the years 2000 and 2001, before and after matching, based on the joint distribution of firms' R&D spending over total assets, firm size as measured by the natural logarithm of total assets, the natural logarithm of Tobin's Q, board size. ***, **, * denote significance level of two sided *t*-tests on the difference between mean values of Panel A and B, and Panel A and C, respectively. *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

changes in board independence, by estimating:

$$log(1 + patents_{i,t+1}) = \beta_0 + \beta_1 \cdot independent\ board_{it} \cdot post_t + \gamma \cdot Z_{it} + \delta \cdot firm_i \cdot pre2002_t \cdot t + \zeta \cdot Z_{it} \cdot post_t + \theta_t + \alpha_i + <_{it}$$

5 Results

First, we present results on innovation measures that have frequently been used by the extant literature on corporate governance and innovation.

5.1 R&D, patents, and citation-weighted patents

Tables 3 to 5 estimate regressions of firms' R&D investments, the number of eventually granted patents applied for, and the number of citation-weighted patent applications. Each table contains 5 specifications of the same model. Specification (a) is a standard OLS model with industry fixed effects, (b) is a standard firm fixed effects model, (c) is the same as (b) but estimated on the previously described balanced sample, (d) adds trend controls, and (e) adds interaction terms of all controls with a post SOX marker. The first model assesses potential changes in R&D investments after board independence changed, which might drive subsequent changes in patenting.[11] The latter two models differentiate between a change in the number of patents and a change in citations to those patents. Cite-weighted patent counts have been shown to correlate with firms' patent portfolio values and patent renewals (Harhoff 1999; and Hall et al., 2005).

Table 3 illustrates that a transition to an independent board is unrelated to the level of firms' R&D investments. In contrast, Tables 4 and 5 illustrate how patenting and total citations both increase. The effect on patenting ranges between a 30.8% and 19.8% increase in number of patents, and a 63.5% to 41.1% increase in citations. Figure 2 illustrates the dynamics of the latter two effects. For the graphs we defined dummy variables for the specific times before and after firms changed to an independent board. t_0 defines the year of the switch and serves as the baseline category, t_{n-1} defines the number of years before the switch, and t_{n+1} the corresponding years after the switch. Then, we ran regressions including these variables instead of the single dummy variable in the baseline model beforehand. As we still include year fixed effects, the coefficients represent the relative change in patenting per year that is attributable to the board change.

[11] Alternative regressions with R&D investments scaled by total assets reveal a significant positive effect only in specifications without firm fixed effects. Inclusion of controls for time invariant firm heterogeneity leads to statistically insignificant results.

Table 3: Independent boards and R&D

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.822***	0.564***	0.601***	0.609***	0.602***
	(0.017)	(0.044)	(0.040)	(0.049)	(0.049)
log(age)	-0.153***	0.002	-0.006	-0.017	-0.013
	(0.021)	(0.029)	(0.038)	(0.056)	(0.054)
Leverage	-0.562***	0.040	-0.085	-0.211	-0.462**
	(0.113)	(0.107)	(0.124)	(0.152)	(0.212)
Cap. exp.	0.753	0.562	0.542	0.378	0.820
	(0.616)	(0.351)	(0.391)	(0.431)	(0.518)
log(Q)	0.366***	-0.016	-0.015	-0.014	0.022
	(0.025)	(0.024)	(0.029)	(0.032)	(0.035)
Boardsize	0.024**	0.007	0.004	0.006	-0.004
	(0.009)	(0.008)	(0.011)	(0.013)	(0.014)
Independent board	0.071	-0.052	-0.057	-0.059	-0.043
	(0.090)	(0.055)	(0.056)	(0.064)	(0.061)
Observations	6107	6107	4414	4414	4414
R^2	0.733	0.256	0.254	0.450	0.508
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is log(R&D). All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 4: Independent boards and no. of patents

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.767***	0.273***	0.284***	0.369***	0.425***
	(0.017)	(0.060)	(0.064)	(0.067)	(0.079)
R&D	5.561***	0.941*	0.842	0.711	0.835
	(0.568)	(0.517)	(0.668)	(0.713)	(0.896)
log(age)	0.105***	0.068	0.000	0.004	-0.019
	(0.023)	(0.044)	(0.039)	(0.048)	(0.058)
Leverage	-0.468***	-0.112	-0.094	-0.253	-0.250
	(0.123)	(0.176)	(0.196)	(0.188)	(0.212)
Cap. exp.	1.635***	0.147	0.127	0.321	0.325
	(0.490)	(0.484)	(0.518)	(0.522)	(0.561)
log(Q)	0.199***	0.057*	0.057	0.081**	0.066
	(0.027)	(0.034)	(0.037)	(0.040)	(0.041)
Boardsize	0.015	0.017	-0.003	-0.016	-0.012
	(0.010)	(0.014)	(0.016)	(0.015)	(0.017)
Independent board	0.308***	0.272***	0.215***	0.208**	0.198**
	(0.083)	(0.079)	(0.080)	(0.087)	(0.087)
Observations	6107	6107	4414	4414	4414
R^2	0.571	0.207	0.176	0.410	0.414
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the no. of eventually granted patents. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 5: Independent boards and no. of cite-weighted patents

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.917***	0.320***	0.276***	0.321***	0.523***
	(0.027)	(0.089)	(0.098)	(0.115)	(0.126)
R&D	7.700***	2.464***	2.706***	3.292***	4.767***
	(0.868)	(0.836)	(1.036)	(1.159)	(1.402)
log(age)	0.142***	0.065	0.006	0.024	-0.056
	(0.038)	(0.056)	(0.058)	(0.080)	(0.089)
Leverage	-0.369*	0.124	0.337	0.203	0.146
	(0.200)	(0.262)	(0.301)	(0.304)	(0.388)
Cap. exp.	2.623***	0.118	0.184	0.551	0.524
	(0.805)	(0.817)	(0.852)	(0.980)	(1.117)
log(Q)	0.355***	0.221***	0.240***	0.244***	0.275***
	(0.046)	(0.055)	(0.061)	(0.076)	(0.085)
Boardsize	0.000	-0.004	-0.029	-0.045*	-0.049
	(0.015)	(0.021)	(0.026)	(0.027)	(0.032)
Independent board	0.594***	0.635***	0.536***	0.423***	0.411***
	(0.128)	(0.116)	(0.119)	(0.137)	(0.139)
Observations	6107	6107	4414	4414	4414
R^2	0.506	0.318	0.286	0.446	0.454
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the no. of citation-weighted patents. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

The results are consistent with classic agency theory and our first hypothesis, suggesting that intensified monitoring leads to increased effort of the agent, which manifests in our case in increased patenting of inventions. That firms patent more, but do not spend more on R&D, raises the question whether firms just work more efficiently with the given resources ('squeeze the lemon harder') or exploit extant knowledge at the expense of less explorative innovation. The arguments for our second hypothesis argue that increased board independence leads to a shift from explorative to more exploitative innovative activities. The following empirical models provide corresponding evidence.

5.2 The distribution of citations

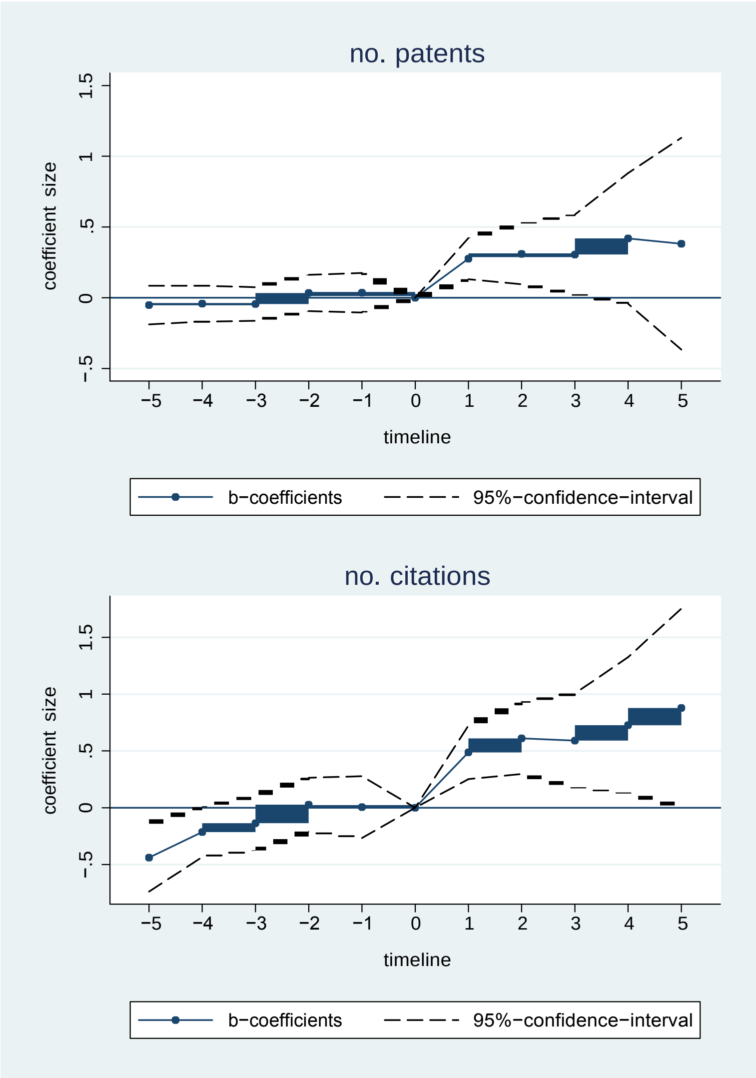
In this section, we model the distribution of citations. Patent citation as well as patent value distributions are highly skewed and the citation-value relationship is most likely not linear. Hence, we split the distribution into subcategories: (1) the number of patents that received cites within the highest percentile (top 1%) among all patents in the same 3-digit patent class and application year, (2) the number of patents that received cites within the highest centile (10%) among all patents in the same 3-digit patent class and application year, (3) the number of patents that received at least one citation (median is 0), and (4) the number of patents that received no citation. Tables 6 to 9 present the corresponding results.

Consistent with the models in Tables 4 and 5 we see a positive effect of board transitions on patenting and citation rates. Interestingly, however, the estimated effect is by far the largest for patents that received at least one citation (but never in the top 10% of the distribution), while the estimated effect on particularly successful patents (top 1% or top 10%) is very small in magnitude and not consistently significant. Taking also into account that the effect on the number of unsuccessful patents (no cites) is most often statistically insignificant, the evidence is consistent with the argument that firms focus on less risky opportunities when the board becomes independent. Inclusion of a measure of backward citations weakens these effects further, implying that the increase in citations is mediated by movement of the firm into more crowded areas of technological search (models not shown but available from first author). In other words, the increase in citations may not correspond to an increase in patent value, rather, it may be an artifact of the exploitation strategy.

5.3 Self and backward citations

In this section, we investigate additional observable implications of our argument, using more nuanced patent measures. First, we focus on the number of citations that each

Figure 2: Dynamics of independent board effect on patents and citations



Notes: These figures illustrate the effect of a change in board independence on patenting and citations over time. For the graphs we defined dummy variables for the time firms changed from a minority of independent board members to an independent board. t_0 indicates the year of the switch and serves as the reference category. t_{n-1} indicate the years before the switch, and t_{n+1} the corresponding years after the switch. Coefficients are taken from the last regression model of section 4.4, but with the t_n dummies instead of the one dummy variable indicating a majority of independent board members.

Table 6: Independent boards and Top 1% patents

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.166***	0.037**	0.056***	0.054***	0.037*
	(0.008)	(0.016)	(0.015)	(0.019)	(0.020)
R&D	0.724***	-0.092	-0.060	-0.045	-0.102
	(0.097)	(0.136)	(0.223)	(0.290)	(0.364)
log(age)	0.036***	0.013	0.004	-0.002	-0.008
	(0.007)	(0.010)	(0.008)	(0.011)	(0.013)
Leverage	-0.198***	-0.049	-0.113***	-0.145**	-0.110
	(0.035)	(0.042)	(0.043)	(0.058)	(0.070)
Cap. exp.	0.489***	-0.109	-0.094	-0.110	-0.049
	(0.150)	(0.118)	(0.107)	(0.130)	(0.152)
log(Q)	0.031***	-0.000	-0.015	-0.021	-0.023
	(0.009)	(0.011)	(0.012)	(0.015)	(0.015)
Boardsize	0.000	0.004	0.000	-0.002	0.002
	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)
Independent board	0.027	0.043*	0.030	0.045*	0.041
	(0.027)	(0.024)	(0.025)	(0.027)	(0.026)
Observations	6107	6107	4414	4414	4414
R^2	0.312	0.009	0.014	0.179	0.182
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the number of patents that fall in the top 1% percentile of the citation distribution within patent class and application year. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 7: Independent boards and Top 10% patents

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.389***	0.103***	0.113***	0.109***	0.058
	(0.014)	(0.030)	(0.032)	(0.035)	(0.038)
R&D	2.283***	0.218	-0.072	-0.120	-0.232
	(0.265)	(0.222)	(0.344)	(0.420)	(0.553)
log(age)	0.072***	0.040**	0.027*	0.030	0.035
	(0.015)	(0.017)	(0.014)	(0.019)	(0.022)
Leverage	-0.300***	0.049	-0.046	-0.079	-0.064
	(0.076)	(0.072)	(0.083)	(0.095)	(0.110)
Cap. exp.	0.997***	-0.236	-0.196	-0.228	-0.068
	(0.330)	(0.207)	(0.219)	(0.228)	(0.277)
log(Q)	0.101***	0.030	0.026	0.034	0.028
	(0.018)	(0.019)	(0.022)	(0.030)	(0.028)
Boardsize	0.003	0.004	-0.004	-0.007	-0.001
	(0.007)	(0.006)	(0.007)	(0.008)	(0.009)
Independent board	0.069	0.064*	0.051	0.062	0.061
	(0.054)	(0.039)	(0.040)	(0.055)	(0.054)
Observations	6107	6107	4414	4414	4414
R^2	0.407	0.017	0.021	0.208	0.214
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the number of patents that fall in the top 10% centile of the citation distribution within patent class and application year. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 8: Independent boards and cited patents, not in top 10%

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.678***	0.268***	0.227***	0.251***	0.316***
	(0.018)	(0.055)	(0.057)	(0.062)	(0.069)
R&D	4.879***	1.123**	0.820	0.857	1.210
	(0.497)	(0.459)	(0.566)	(0.615)	(0.755)
log(age)	0.097***	0.045	0.001	0.004	-0.024
	(0.023)	(0.034)	(0.032)	(0.041)	(0.048)
Leverage	-0.433***	-0.045	-0.031	-0.103	-0.064
	(0.116)	(0.148)	(0.157)	(0.162)	(0.189)
Cap. exp.	2.093***	0.284	0.407	0.553	0.544
	(0.481)	(0.401)	(0.419)	(0.455)	(0.519)
log(Q)	0.183***	0.091***	0.103***	0.097***	0.090**
	(0.027)	(0.031)	(0.032)	(0.037)	(0.039)
Boardsize	0.004	0.009	-0.003	-0.016	-0.014
	(0.009)	(0.012)	(0.014)	(0.014)	(0.016)
Independent board	0.348***	0.339***	0.260***	0.229***	0.220***
	(0.076)	(0.067)	(0.067)	(0.073)	(0.074)
Observations	6107	6107	4414	4414	4414
R^2	0.536	0.248	0.207	0.416	0.421
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the number of patents that are cited but do not fall in the top 10% of the citation distribution. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 9: Independent boards and patents without citations

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.635***	0.223***	0.278***	0.390***	0.299***
	(0.015)	(0.068)	(0.075)	(0.081)	(0.095)
R&D	3.953***	0.184	-0.206	-0.677	-1.452
	(0.433)	(0.557)	(0.868)	(0.990)	(1.322)
log(age)	0.085***	0.071	-0.011	-0.004	-0.025
	(0.019)	(0.047)	(0.039)	(0.051)	(0.066)
Leverage	-0.418***	-0.233	-0.299	-0.492**	-0.273
	(0.103)	(0.175)	(0.209)	(0.217)	(0.244)
Cap. exp.	1.043***	-0.264	-0.304	-0.338	-0.343
	(0.400)	(0.472)	(0.513)	(0.532)	(0.568)
log(Q)	0.114***	0.003	-0.012	0.006	-0.025
	(0.023)	(0.035)	(0.040)	(0.044)	(0.043)
Boardsize	0.019**	0.028*	0.010	-0.000	0.003
	(0.008)	(0.015)	(0.015)	(0.015)	(0.018)
Independent board	0.167**	0.106	0.077	0.099	0.098
	(0.071)	(0.089)	(0.090)	(0.094)	(0.091)
Observations	6107	6107	4414	4414	4414
R^2	0.510	0.045	0.040	0.323	0.332
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the number of patents that are not cited. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

patent makes to other patents. An increase in the number of backward citations reflects more prior art that must be specified in the patent application. This should correlate with innovative search in relatively better-known and mature technological areas. Second, we take the number of times a given patent cites other patents owned by the same company. More self-cites indicate constraining search within previously known areas of expertise while fewer self-citations indicate a broadening of innovative search or efforts to explore areas that are new to the firm (Sorenson and Stuart, 2000). Table 10 and 11 present the corresponding results.[12] Figure 3 illustrates the dynamics of the effects.

The results presented in Tables 10 and 11 and Figure 3 supports the argument that firms with independent boards tend to narrow their innovative search towards known and mature technological areas.

5.4 Technology classes

We now turn to the number of patents that are filed in classes previously unknown to the firm. Unknown patent classes are defined as those in which a given firm has not been granted any patent back to 1976. The complement is the number of patents applied for in known classes. A more sophisticated measure of whether firms stay or deviate from known research areas is the technological proximity between the patents filed in year *t* and the existing patent portfolio held by the same firm up to year *t*-1 (Jaffe 1989).

Tables 12 to 14 present the corresponding regression results. Figure 4 illustrates the dynamics of the effects on patents in known and unknown areas. As can be seen, independent boards have an insignificant effect on exploration of new classes but a strong and significantly positive effect on search in previously patented classes. The Jaffe measure of technological proximity demonstrates consistent but not always significant results.

6 Discussion and robustness checks

As we discussed in the introduction, several mechanisms could cause a firm whose board becomes independent to exploit current technologies at the expense of searching for new technologies. For example, a manager may (i) work harder in response to greater oversight; (ii) focus on producing more quantifiable outcomes in response to performance pressures; (iii) take less risk out of career concerns; (iv) search less because they fear an independent board will constrain future flexibility. Disentangling

[12] Alternative untabulated regressions of non-self citations reveal very similar results as estimated for the total number of backward citations.

Table 10: Independent boards and backward citations

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	1.030***	0.399***	0.383***	0.556***	0.535***
	(0.031)	(0.106)	(0.119)	(0.134)	(0.148)
R&D	8.023***	1.155	1.117	1.342	0.465
	(0.932)	(1.032)	(1.211)	(1.394)	(1.359)
log(age)	0.133***	0.017	-0.022	0.009	-0.102
	(0.045)	(0.064)	(0.076)	(0.094)	(0.106)
Leverage	-0.231	0.213	0.251	-0.137	-0.052
	(0.238)	(0.304)	(0.356)	(0.363)	(0.439)
Cap. exp.	2.028**	0.085	0.044	0.382	0.515
	(0.915)	(0.958)	(1.007)	(1.099)	(1.225)
log(Q)	0.305***	0.127**	0.160**	0.188**	0.183**
	(0.052)	(0.063)	(0.070)	(0.083)	(0.091)
Boardsize	0.002	-0.002	-0.021	-0.041	-0.044
	(0.018)	(0.023)	(0.028)	(0.030)	(0.035)
Independent board	0.498***	0.479***	0.482***	0.389**	0.388**
	(0.159)	(0.133)	(0.139)	(0.173)	(0.174)
Observations	6107	6107	4414	4414	4414
R^2	0.450	0.115	0.106	0.295	0.298
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

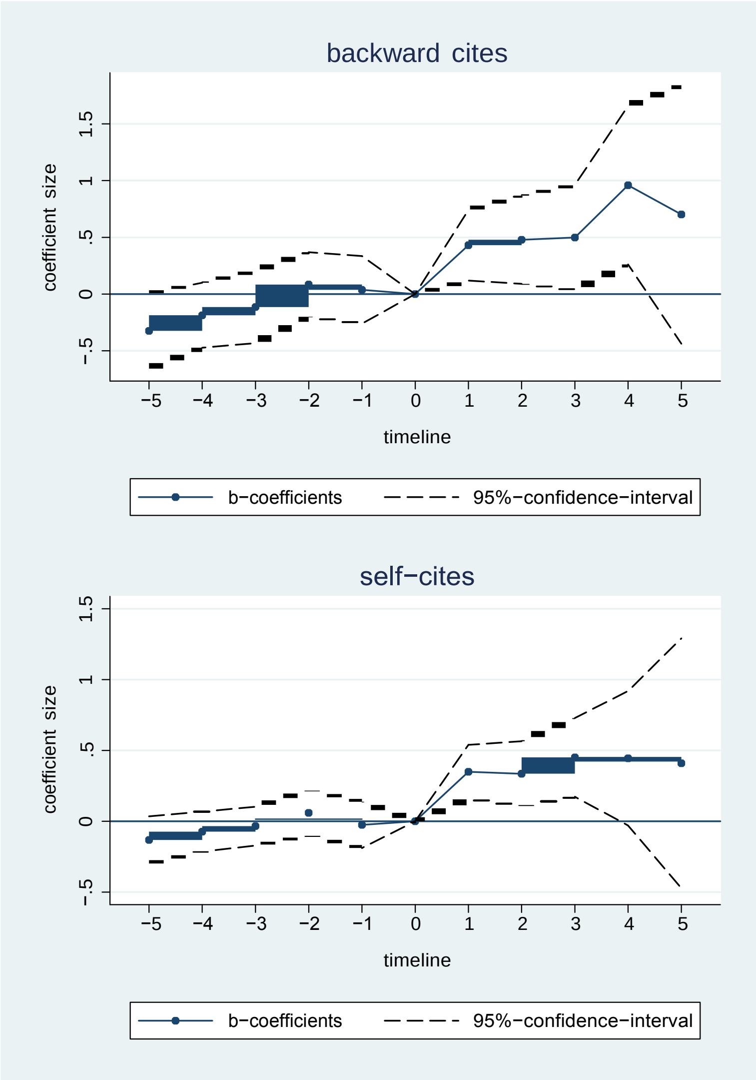
Notes: The dependent variable is the logarithm of one plus the number of backward citations. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 11: Independent boards and self-citations

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.833***	0.204***	0.160**	0.244***	0.244**
	(0.024)	(0.071)	(0.072)	(0.085)	(0.099)
R&D	5.728***	0.234	-0.104	-0.233	-0.585
	(0.636)	(0.671)	(0.835)	(1.056)	(1.106)
log(age)	0.158***	0.075	0.013	0.030	0.000
	(0.031)	(0.047)	(0.045)	(0.060)	(0.071)
Leverage	-0.321*	0.004	-0.014	-0.275	-0.154
	(0.170)	(0.228)	(0.257)	(0.264)	(0.346)
Cap. exp.	3.488***	0.853	0.761	1.017	1.240
	(0.672)	(0.580)	(0.595)	(0.703)	(0.829)
log(Q)	0.269***	0.035	0.038	0.059	0.075
	(0.038)	(0.042)	(0.043)	(0.047)	(0.053)
Boardsize	0.018	0.023	0.010	-0.013	-0.017
	(0.013)	(0.015)	(0.018)	(0.018)	(0.022)
Independent board	0.389***	0.359***	0.284***	0.260***	0.262***
	(0.109)	(0.080)	(0.081)	(0.096)	(0.096)
Observations	6107	6107	4414	4414	4414
R^2	0.469	0.088	0.061	0.285	0.286
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the number of backward citations. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Figure 3: Dynamics of independent board effect on backward and self-citations



Notes: These figures illustrate the effect of a change in board independence on backward and self-citations over time. For the graphs we defined dummy variables for the time firms changed from a minority of independent board members to an independent board. t_0 indicates the year of the switch and serves as the reference category. t_{n-1} indicate the years before the switch, and t_{n+1} the corresponding years after the switch. Coefficients are taken from the last regression in 4.4, but with the t_n dummies instead of the one dummy variable indicating a majority of independent board members.

Table 12: Independent boards and patents in known classes

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.779***	0.275***	0.290***	0.368***	0.431***
	(0.018)	(0.059)	(0.063)	(0.066)	(0.078)
R&D	5.718***	0.989*	0.743	0.534	0.649
	(0.572)	(0.527)	(0.678)	(0.732)	(0.943)
log(age)	0.107***	0.061	-0.018	-0.020	-0.038
	(0.023)	(0.046)	(0.040)	(0.050)	(0.059)
Leverage	-0.521***	-0.206	-0.217	-0.383**	-0.390*
	(0.124)	(0.179)	(0.200)	(0.191)	(0.221)
Cap. exp.	1.622***	-0.009	0.056	0.122	0.167
	(0.500)	(0.471)	(0.510)	(0.501)	(0.553)
log(Q)	0.214***	0.059*	0.064*	0.091**	0.080*
	(0.028)	(0.034)	(0.037)	(0.040)	(0.042)
Boardsize	0.018*	0.023	0.006	-0.005	-0.001
	(0.010)	(0.014)	(0.016)	(0.015)	(0.017)
Independent board	0.323***	0.289***	0.231***	0.209**	0.198**
	(0.082)	(0.079)	(0.079)	(0.083)	(0.083)
Observations	6107	6107	4414	4414	4414
R^2	0.572	0.184	0.153	0.401	0.406
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the number of patents filed in classes where the given firm had already at least on other patent filed any previous year. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 13: Independent boards and patents in unknown classes

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.171***	0.096***	0.103***	0.101**	0.177***
	(0.008)	(0.032)	(0.037)	(0.042)	(0.045)
R&D	0.994***	0.329	0.508	0.516	1.039**
	(0.175)	(0.270)	(0.379)	(0.472)	(0.494)
log(age)	-0.002	0.018	0.025	0.032	0.021
	(0.010)	(0.019)	(0.021)	(0.025)	(0.029)
Leverage	-0.091*	0.099	0.104	0.099	-0.011
	(0.055)	(0.086)	(0.098)	(0.115)	(0.134)
Cap. exp.	0.958***	0.916***	0.802**	0.866**	0.975**
	(0.239)	(0.303)	(0.322)	(0.389)	(0.443)
log(Q)	0.062***	0.064***	0.053***	0.026	0.012
	(0.012)	(0.019)	(0.020)	(0.025)	(0.027)
Boardsize	0.002	0.004	-0.004	-0.009	-0.012
	(0.005)	(0.008)	(0.011)	(0.012)	(0.012)
Independent board	0.088**	0.055	0.023	0.037	0.036
	(0.036)	(0.045)	(0.044)	(0.053)	(0.052)
Observations	6107	6107	4414	4414	4414
R^2	0.319	0.134	0.115	0.284	0.291
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

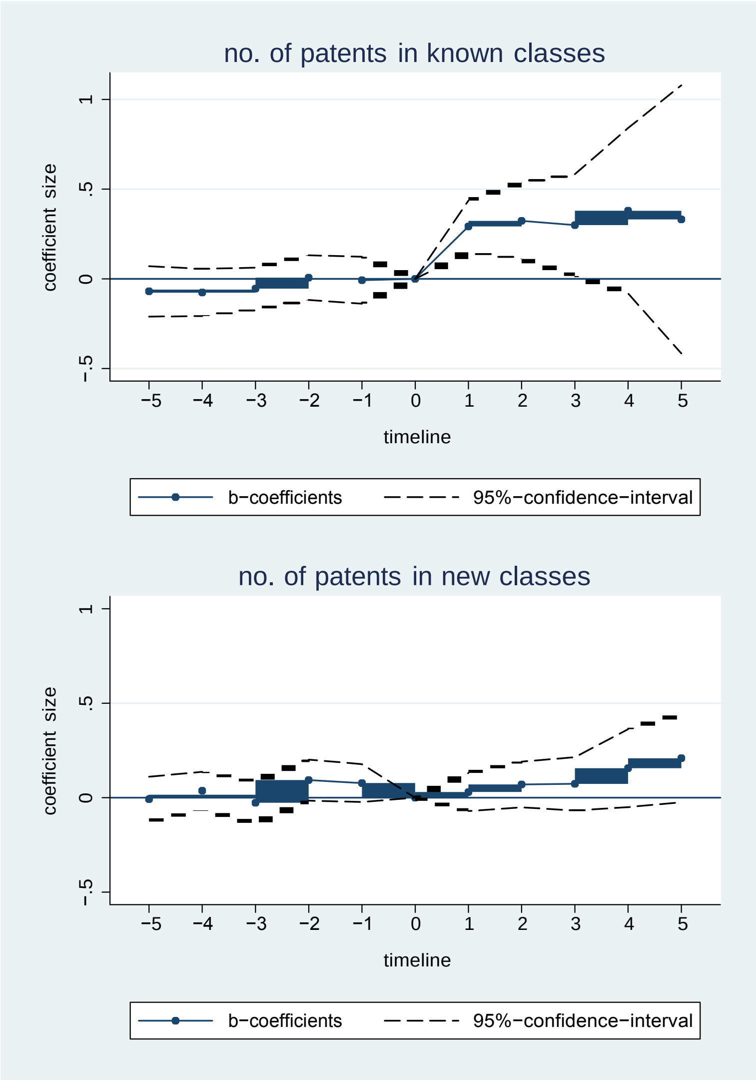
Notes: The dependent variable is the logarithm of one plus the number of patents filed in classes where the given firm had no other patent filed in any previous year. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 14: Independent boards and technological proximity

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.451***	0.187**	0.224**	0.363***	0.306**
	(0.020)	(0.085)	(0.100)	(0.117)	(0.124)
R&D	5.353***	0.859	0.976	0.820	0.033
	(0.710)	(0.835)	(1.018)	(1.104)	(1.132)
log(age)	0.085***	-0.005	-0.024	-0.021	-0.049
	(0.030)	(0.052)	(0.063)	(0.077)	(0.081)
Leverage	-0.020	-0.138	-0.075	-0.448	-0.472
	(0.172)	(0.263)	(0.313)	(0.344)	(0.428)
Cap. exp.	-0.280	-0.179	-0.362	-0.228	-0.161
	(0.663)	(0.856)	(0.937)	(0.944)	(1.055)
log(Q)	0.177***	0.038	0.061	0.100	0.097
	(0.036)	(0.048)	(0.057)	(0.066)	(0.074)
Boardsize	0.014	0.023	0.011	0.010	0.022
	(0.012)	(0.018)	(0.022)	(0.025)	(0.030)
Independent board	0.247**	0.255**	0.289**	0.177	0.169
	(0.115)	(0.120)	(0.126)	(0.138)	(0.140)
Observations	6107	6107	4414	4414	4414
R^2	0.369	0.118	0.112	0.292	0.294
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the technological proximity between the patents filed in year t to the existing patent portfolio held by the same firm up to year t-1, and is calculated according to Jaffe (1989). All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Figure 4: Dynamics of independent board effect on patents in known and unknown classes



Notes: These figures illustrate the effect of a change in board independence on patents filed in known and unknown classes over time. For the graphs we defined dummy variables for the time firms changed from a minority of independent board members to an independent board. t_0 indicates the year of the switch and serves as the reference category. t_{n-1} indicate the years before the switch, and t_{n+1} the corresponding years after the switch. Coefficients are taken from the last regression of 4.4, but with the t_n dummies instead of the one dummy variable indicating a majority of independent board members.

these mechanisms empirically remains difficult, as they imply similar predictions and probably co-exist in practice. Hence, we provide only suggestive evidence on the various mechanisms.

An independent board may be more effective at ameliorating moral hazard and decreasing shirking; if this were the case, then one would expect greater effort from the manager under an independent board. In the context of innovation and patenting, this would correspond to greater (and/or more efficient) research and development, innovation and patenting, and performance. As presented above, we found no convincing evidence that points to a change in the amount of research and development investment; the descriptive statistics do not provide a clear picture and the econometric models are mostly insignificant. Again from the tables above the evidence is consistent that firms that transition to independent boards do receive more patents. Supplementary regressions further indicate that the process is not more efficient - there is no statistically significant result for the regression of patents per R&D investment (not shown). This is consistent with other research that has found mixed evidence for the impact of independent boards on overall performance (see e.g. Duchin, Matsusaka, and Oguzhan, 2010; Nguyen and Nielsen, 2010) that is context dependent, as argued in Adams, Hermalin, and Weisbach (2010) and empirically confirmed by Duchin, Matsusaka, and Oguzhan, (2010). In the current work, models including Tobin's Q and labor productivity (the logarithm of sales/employee) were also robust to these controls. Hence, while independent boards may indeed make their managers work harder, and this is reflected in greater patenting, that mechanism does not appear to drive the strategic shift towards exploitation shown above.

In addition to pressuring their manager to work harder, boards may ask them to justify and quantify their results. Given that independent board members are by definition from outside the firm and possibly the industry, it is likely that independent board members are less familiar with the firm's business and technologies. Hence, it is reasonable that they would ask for easily interpreted measures, such as patent counts and accounting based performance measures. In order to investigate these possibilities, we split the sample into firms with high and low return on assets (ROA), under the assumption that managers of low performing firms will be more sensitive to board control and under greater pressure to produce quantifiable results. Consistent with this assumption, the results are consistently stronger for firms with low ROA though not always significantly different across the split samples (full results are available from the authors).

Independent boards may increase career concerns of managers and reduce their future flexibility, leading to lower exploration and potentially less innovative activity in general. The evidence of increased patenting and no effect on R&D spending does not support this - managers are not retreating from all types of innovative search. In order to investigate how our results relate to career concerns and flexibility we re-estimated all our models splitting the sample into firms with high and low managerial entrenchment, using the index of Bebchuk, Cohen, and Ferrell (2009). This entrenchment or "e-index" indicates how many corporate governance provisions are in place that shield a manager from getting fired, e.g. poison pills, golden parachutes, and supermajority requirements for mergers and charter amendments. [13] Our results show that the effects of independent boards are consistently stronger for firms with high managerial entrenchment, though again, they are not always significantly different across the split samples (full results also available).

At first sight this seems to suggest against a career concerns and flexibility story, as it is entrenched managers with weak career concerns and high autonomy that drive most of the results. However, one can argue that managers in firms with low entrenchment index are already subject to career concerns and takeover pressures, even before the board becomes independent. Therefore, the transition to an independent board does not have much impact on these managers. It is for entrenched managers that transitioning into independent boards can trigger career concerns and loss of flexibility.

The aggregate evidence is consistent with different mechanisms and thus inconclusive. Most likely all three mechanisms (career concerns, autonomy, and pressure for quantifiable results) play a role in explaining our results on innovation search strategy.

The fact that firms which transition to independent boards patent more raises the concern that the backward and self citation results might simply be artifacts of the increased patenting. To address this, we estimate regressions of backward and self-citations per patent. As can be seen in Tables 15 and 16 in the Appendix, the results are not merely an artifact of increased patenting. The proportion of backward and self-citations also increases for firms which transition to independent boards.

Finally, we considered the coefficient of variance of citations to firms that undergo the transition to independent boards. While the results were not significant on a yearly basis, an aggregation of the four years following the transition demonstrated a significant decrease; citations to firms with independent boards become less variable after the transition. This result follows from the argument of exploration vs. exploitation; it does not follow from a manager working harder or attempting to better quantify their results.

The greatest empirical contribution of the work is to provide easily calculated measures which differentiate between greater innovative effort and greater innovative nov-

[13] The E-Index is given by Bebchuk, Cohen and Ferrell (2009) for all equal years and is fairly stable over time. In order to keep the sample size as large as possible we imputed with the lagged value where the E-Index was missing; if the lagged value was missing we took the forward value.

elty and search. Firms can increase their patent counts - and even future citations to those patents - by exploiting their current technologies and without searching new technologies. The consistent empirical results give pause to the assumption that increased patenting and citations provides a complete measure of risky and innovative search. The recent surge of research in the finance literature might be profitably re-examined by differentiating between greater effort and greater exploration.

7 Conclusion

We demonstrated that firms which undergo a transition to more independent boards will invent more patents but that those patents will be less creative. We argued that this tendency towards exploitation results from stronger board oversight and offered a variety of mechanisms, including greater effort by the manager, attempts to quantify outcomes, career concerns, and decreased search on the part of the manager who fears the loss of future strategic flexibility.

Evidence to support these arguments comes from regulatory changes which forced boards to become more independent. Following the observable implications of our informal model, firms whose boards become more independent are less likely to explore new technologies and more likely to exploit previously successful areas of expertise. Consistent with a strategy of exploitation, firms that transition to more independent boards get more but less creative patents. On average the patents are cited more, however, those citations are made to patents in the middle of the distribution, and not to breakthrough or completely failed patents. Firms with more independent boards work in more crowded and more familiar areas of technology.

These more nuanced measures of search and exploration enable greater insight into the search and innovation process and highlight the importance of differentiating between greater effort and incremental output vs. breakthrough inventions. Further work should differentiate, both theoretically and empirically, between greater effort and riskier exploration; it should not assume that an increase in patent counts implies an increase in risk-taking and creativity.

Independent boards appear to move firms towards innovative exploitation, but is that bad for performance? Other research has found mixed evidence for the impact of independent boards on overall performance (see e.g. Duchin, Matsusaka, and Oguzhan, 2010; Nguyen and Nielsen, 2010; Adams, Hermalin, and Weisbach; Duchin, Matsusaka, and Oguzhan, 2010). Lack of exploration may cause long term obsolescence and competency traps, but where is the optimal tradeoff? That is the topic for future research.

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8 Appendix: robustness checks

Tables 15 and 16 report average number of backward and self citations, demonstrating that firms' exploitation is not an artifact of greater patenting.

Table 15: Independent boards and average no. of backward cites

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	-0.059**	0.055	0.042	0.031	0.021
	(0.028)	(0.050)	(0.057)	(0.073)	(0.081)
R&D	0.110***	-0.006	-0.015	-0.010	-0.008
	(0.022)	(0.029)	(0.031)	(0.045)	(0.047)
log(age)	-0.019	0.006	0.002	0.043	-0.014
	(0.025)	(0.036)	(0.044)	(0.055)	(0.067)
Leverage	0.272**	0.017	-0.005	-0.204	-0.286
	(0.137)	(0.149)	(0.185)	(0.232)	(0.288)
Cap. exp.	0.724	0.761	0.720	0.138	0.276
	(0.542)	(0.501)	(0.551)	(0.752)	(0.761)
log(Q)	0.073**	0.033	0.050	0.034	0.042
	(0.029)	(0.030)	(0.036)	(0.043)	(0.049)
Boardsize	-0.017	-0.004	-0.002	-0.013	-0.018
	(0.011)	(0.011)	(0.016)	(0.019)	(0.025)
log(sales/employee)	-0.151***	0.058	0.076	0.092	0.117
	(0.049)	(0.073)	(0.094)	(0.123)	(0.127)
ROA	0.523**	-0.295	-0.530	-0.170	-0.207
	(0.219)	(0.270)	(0.364)	(0.420)	(0.428)
E-Index	-0.007	-0.054	-0.069	-0.076	-0.057
	(0.017)	(0.040)	(0.054)	(0.080)	(0.078)
Independent board	0.229**	0.154*	0.190**	0.161	0.166
	(0.108)	(0.088)	(0.090)	(0.110)	(0.112)
Observations	3791	3791	2558	2558	2558
R^2	0.228	0.023	0.019	0.268	0.272
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the average number of backward citations per patent. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.

Table 16: Independent boards and average no. of self-cites

	(a) b/se	(b) b/se	(c) b/se	(d) b/se	(e) b/se
log(total assets)	0.017	-0.033	-0.034	0.033	0.044
	(0.014)	(0.037)	(0.044)	(0.064)	(0.070)
R&D	0.080***	-0.001	0.002	-0.012	-0.014
	(0.011)	(0.023)	(0.024)	(0.037)	(0.040)
log(age)	0.038**	0.030	0.020	0.009	0.008
	(0.015)	(0.023)	(0.029)	(0.036)	(0.037)
Leverage	0.150*	-0.069	-0.155	-0.300	-0.267
	(0.089)	(0.120)	(0.153)	(0.196)	(0.247)
Cap. exp.	1.353***	0.638*	0.579	0.488	0.492
	(0.340)	(0.369)	(0.426)	(0.602)	(0.624)
log(Q)	0.113***	0.001	-0.024	0.004	0.015
	(0.018)	(0.019)	(0.024)	(0.032)	(0.036)
Boardsize	0.005	0.017**	0.013	0.003	-0.004
	(0.007)	(0.007)	(0.009)	(0.011)	(0.013)
log(sales/employee)	-0.108***	0.035	0.055	0.059	0.064
	(0.031)	(0.058)	(0.076)	(0.101)	(0.102)
ROA	-0.004	-0.267*	-0.217	-0.231	-0.244
	(0.148)	(0.154)	(0.204)	(0.237)	(0.231)
E-Index	0.002	-0.036	-0.054*	-0.046	-0.041
	(0.011)	(0.022)	(0.030)	(0.041)	(0.041)
Independent board	0.158**	0.171***	0.169***	0.133*	0.137*
	(0.067)	(0.052)	(0.054)	(0.071)	(0.070)
Observations	3791	3791	2558	2558	2558
R^2	0.245	0.025	0.030	0.233	0.234
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	No	Yes	Yes	Yes	Yes
Trend control	No	No	No	Yes	Yes
Controls * post-SOX	No	No	No	No	Yes

Notes: The dependent variable is the logarithm of one plus the average number of self-citations per patent. All explanatory variables are lagged by one period. Specification (a) includes untabulated 3-digit SIC industry dummies and a dummy that marks all treated firms. Independent board is a dummy that indicates firms after they switched from a minority of independent board members to a majority of independent board members in 2001 or later. Control variables are defined in section 4.2. Heteroskedasticity-robust standard errors that account for autocorrelation at the firm level are reported in parentheses. Coefficients: *** Significant at 1%, ** Significant at 5% level, * Significant at 10% level.