DO BOARD INTERLOCKS INCREASE INNOVATION? EVIDENCE FROM NATURAL EXPERIMENTS IN INDIA*

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ABSTRACT

We examine the effect of board interlocks on patenting and R&D spending for publicly traded companies in India. We exploit two natural experiments to address endogeneity: an exogenous governance reform requiring a subset of firms to adjust their board structure and an exogenous change to the patent system that affected patentability for a subset of companies. Board interlocks have significant positive effects on both R&D and patenting. The impact on R&D is attributable to an innovation effect induced by information transmission through interlocks. The effect on patenting is driven by a strategic effect. Firms are more likely to extend patent protection by patenting inventions abroad that they have already patented in India.

KEYWORDS: Patents, peer effects, director networks, innovation, India, natural experiments

JEL Classification: G3, O16, O34, O31

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1 INTRODUCTION

Directors on the boards of firms play several roles. While their primary role on a particular board may be to monitor the management of their employing firm on behalf of shareholders, directors can also be interlocked, serving on many boards concurrently. Pfeffer and Salancik (2003) note that interlocked directors provide additional resources to the firm such as legitimacy, skills, information, and links to customers, suppliers, capital providers, and other stakeholders. Hillman and Dalziel (2003) argue that connected directors can provide these resources because of their own human capital, related to their experience and expertise, and because of their relational capital associated with social ties to other firms' directors. Coles, Daniel, and Naveen (2012) argue that the quality of the board's advice depends on the number of connections the outside directors have with directors at other firms, since connected directors are likely to have better access to information on market conditions.

The empirical literature offers mixed evidence as to whether these connections reduce or enhance shareholder (as opposed to managerial) value. Connections may enhance the board's advising ability but reduce its efficacy in preventing managerial agency problems. For example, Barnea and Guedj (2007) and Hwang and Kim (2009) report that firms with more connected directors pay their CEOs more, and are less likely to force CEO turnover in cases of poor performance. Fracassi and Tate (2012) argue that CEO–director ties reduce firm value because they reduce the intensity of board monitoring. Boards with more interlocked directors could also be poor monitors because they are too busy to keep an eye on management (Fich and Shivdasani 2006). In contrast, other studies argue that connected boards indeed enhance shareholder value. For example Larcker, So, and Wang (2013) show that firms with central boards of directors earn superior risk-adjusted returns and Chuluun et al. (2013) documents that highly connected boards reduce information asymmetry between firms and debtholders and consequently reduce the cost of debt capital.

In this paper, we examine how interlocking boards transfer *information* across firms, a topic that has not been examined in the prior literature. Specifically, we analyze whether board interlocks affect firm innovation activities through a network size effect, that is, through the number of links a company has with other companies because of interlocking directors. Our analysis is conducted on a large sample of Indian firms in innovative industries between 2000-2007, a period coinciding with exogenous changes in regulation on board composition and patenting. We examine the impact of regulatory-driven changes in corporate network size on a company's innovative activities measured by R&D expenditure, as well as its domestic and international patenting behavior.

This is an important issue. Westphal and Frederickson (2001) show that directors conceive changes in corporate strategy that reflect the strategies of their own home companies, and select new CEOs who have prior experience with similar strategies to facilitate implementation. They also show that while the experience of new CEOs appears to predict corporate strategic change, these effects disappear after accounting for board experience. They argue that executive effects on strategy can mask board effects. One of the key strategic decisions for which the board of directors is responsible, is the firm's level of investment in innovation, including its approach to knowledge and intellectual property (IP) management. *A priori*, it may appear unlikely that board directors are directly involved at the level of determining R&D activities since they are unlikely to have as much technology expertise as the researchers in the companies they govern. However, given the number of items on a typical board agenda, it is plausible that board members contribute to raising the importance and attention allocated to specific R&D directions set by the firm. Specifically, while a board member is unlikely to suggest a brand new direction for innovation or R&D, it is likely for the member to suggest that the firm pay greater attention to some innovative activities over others.[1] The larger the network size of the board, the more exposed directors are likely to be on innovative trends in the industry and the more likely they are to suggest changes in emphasis on the specific innovative activities of the firm.

The need for such direct board oversight of IP matters has increased enormously over the past decade and a half as the stakes involved in IP have often become critical. IP, in particular in the form of patents, assumes an important role both as a highly valuable, albeit uncertain, intangible asset and as a strategic tool or threat in high-stake litigation.[2] IP related concerns often also play a role in M&A decisions – a core competence of directors – where companies choose their targets at least in part based on their targets' patent portfolios. The provision of information is vital to undertaking such IP related decisions because managers often face a fair amount of uncertainty with regard to the eventual viability/success of specific actions and investments. We examine whether interlocked

[1] Based on our conversations with board members. In addition, all board members usually weigh in on the business model, which includes the level of R&D as a percentage of overall revenues and try and influence the productivity of R&D with ideas on outsourcing, offshoring, or acquisitions. Board members typically attempt to foster innovation, for example, by increasing firm focus on developing intellectual property and encouraging patent applications.

[2] Sterne and Chaplick (2005) argue that under U.S. corporate governance law, lack of direct oversight of IP matters by a company's directors exposes the board to legal liability for failure of oversight.

directors facilitate these decisions by sharing information across firms.

As noted in Stuart and Yim (2010), there are two major issues with most of the literature on networked boards. One is the question of reverse causality – that firms hire directors because they need help in taking a particular decision, and not because the directors influence the firm to take the decision.[3] It is plausible, for example, that a firm that wishes to acquire a target company would prefer to hire a director with experience at prior acquirers. Baker and Gompers (2003) and Shivdasani and Yermack (1999) among others, document how CEOs influence the board selection process to hire directors of their choice. The second is the question of the director-firm match. Directors and firms do not match randomly. Do, Nguyen, and Rau (2014) show that boards and firms match assortatively on a number of characteristics such as size. They document, for example, that better qualified directors join larger firms. The issue here is that the presence of a director on two separate boards merely reflects an underlying similarity between the two firms and this similarity causes the two firms to behave similarly. The prior literature typically addresses these issues by examining changes in firm behavior following changes in directors at the firms, usually with a lag long enough to reduce the likelihood of reverse causality.[4]

In our context, similar innovative activity between networked firms could in part reflect a tendency by high inventive capacity firms to simultaneously work on similar recent technological developments, rather than being influenced to do so by a shared board member who transfers information across them. Alternatively, a firm could employ a board member from a technologically superior firm precisely to take advantage of the other firm's knowledge base, rather than the board member providing that information after arrival and influencing the firm to alter its innovative activity. These types of strategic behavior, associated with network formation, but unobservable to the econometrician, confound estimates of network effects.

To identify the network size effect and the underlying mechanisms, we rely on two natural experiments. The first derives from a recently introduced corporate governance reform in India that required a subset of Indian firms to attain, among other things, a specified board structure. Firms that were required to comply with this reform witnessed a substantial change in their network size because they were forced to restructure their board composition and appoint new non-executive

[3] For a detailed discussion of the reverse causality and endogeneity problems when studying board structure, see Adams, Hermalin, and Weisbach (2010).

[4] For example, Stuart and Yim (2010) shows that PE interlocked directors typically have many years of tenure on the board when a private equity offer arrives. Fracassi and Tate (2012) analyze director exits due to deaths and retirements.

directors on their board. We rely on a differences-in-differences framework, comparing firms that fell short of the board restructuring requirement and those that did not at the time of the reform. As an alternative, we rely on a regression discontinuity design, exploiting the threshold related to board composition that determined whether firms were required to adjust. Both approaches yield similar results. Hence in the first stage, our instrument is the threshold for the policy reform that applied to a subset of firms uniformly. Differences across the subset are absorbed either by firm-fixed effects (our differences-in-differences framework) or non-parametrically by an analysis of the close neighbourhood around the threshold (our RDD strategy).

As an example to illustrate this process, following the reform, Tube Investments of India Ltd. (operating in the base metals industry) was required to adjust its board structure in 2002 and hired Mr. M. M. Murugappan who was concurrently serving as a director at Mahindra & Mahindra Ltd (operating in the transport equipment industry). Mahindra & Mahindra was much larger than Tube Investments. Its R&D expenditure at the time Tube Investments hired Mr. M. M. Murugappan was INR 689.6 million (approximately US$ 15.3 million).[5] In comparison, the R&D expenditure of Tube Investments before hiring Mr. M. M. Murugappan was INR 17.6 million (approximately US$ 390,000). After Mr. Murugappan joined them, their R&D expenditure increased to INR 23.8 million (US$ 530,000) by the end of 2004, an increase of approximately 35 percent. A significant portion of this investment was spent on improving the quality of the cycles division of the company.[6] In contrast, the average *industry* R&D for Tube Investments at this time was INR 7.64 million (US$ 170,000). We exploit this type of exogenously mandated variation to predict the network size for firms and find that firms with larger networks patent and spend more on R&D than firms with less interconnected boards of directors.

While the corporate governance reform addresses the endogeneity of network size, it does not reveal the underlying *mechanism* driving the influence of network size on R&D and patenting. Specifically, we would like to investigate if the effect of network size on firm R&D and patenting is driven by peer effects from other companies within a firm's corporate network. However, since the peer effect depends crucially on the *composition* of the network, independent of its size, the corporate governance reform cannot by itself act as an instrument for endogenous peer effects.

[5] Throughout the paper, we use the year 2000 US$-INR exchange rate for converting figures measured in Indian Rupees (INR) to their US dollar equivalent (US$).

[6] See for example, Ramesh, M., 2003, "'We are targeting Rs 80-cr exports in the current year' – Mr. K Balasubramanian, VP-Finance, Tube Investment of India", *Business Line* (The *Hindu*), 11 June 2003.

More precisely, the corporate governance reform forces firms to increase the proportion of independent directors. However, firms facing this requirement still have the choice of whether the new directors are networked or not. For example, a better performing or more innovative firm (or firms that wished to be more innovative) could strategically choose networked directors when forced by the reform to bring in new directors.[7] Again, going back to Mr. Murugappan's case, since Tube Investments was spending significantly more on R&D than the average firm in the industry and since it already had a cycles division, it is plausible that it was also significantly more likely to hire a director from a high-innovation firm in the transportation industry.

To identify whether firm research and patenting activities are indeed exogenously affected by the change in network composition, we therefore make use of a second natural experiment, specifically a fundamental exogenous change to the Indian patent system. India's World Trade Organization (WTO) accession in 1995 forced the government to re-align its patent system with TRIPS (Agreement on Trade Related Aspects of Intellectual Property Rights), which in particular allowed for the patentability of pharmaceutical and chemical product inventions. We exploit the joint interaction effect of the board restructuring reform and the TRIPS patent reform to obtain two different sources of variation: cross sectional variation from differing board restructuring requirements of firms and time series variation from the TRIPS reform that exogenously broadened the ability of pharmaceutical and chemical firms to patent. Our joint interaction instrument, therefore, induces a positive upward shift in the average R&D and patenting of network firms engaged in pharmaceutical/chemical activities which allows us to identify the exogenous impact of network composition on patenting and R&D activity. For this identification strategy to work, we use only the sample of *non*-pharmaceutical/chemical firms whose patenting and research activity was not directly affected by the TRIPS reform since it did not apply to them. Any increases in patenting and research activity for these firms is therefore more likely to be driven by the connections these firms have to pharmaceutical/chemical firms. We document positive and significant peer effects of average R&D spending of a firm's corporate network on its own R&D spending. This suggests that the positive network size effect can be explained, in part, by positive spillovers in research activity that are generated within

[7] We note this issue is also faced by other academic studies that use similar natural experiments to identify the effect of boards on firm decisions. For example, Coles, Daniel, and Naveen (2013) use the change in Nasdaq and NYSE rules in 2002 requiring all firms listed on the two exchanges to have a majority of independent directors on their board as an instrument to identify the effect of board co-option on pay. Similar to our board restructuring regulation instrument, this instrument cannot identify *why* co-opted boards have a lower intensity of board monitoring.

the corporate network.

As an example, to illustrate this process, in 2005, Titan Industries Ltd., a reform-affected firm (operating in the consumer durables industry) hired Mr. Arun Ramanathan and Mr. P. Baskaradoss, both of whom served on the board of Tanfac Industries Ltd. (operating in the chemicals industry). The average R&D expenditure for Tanfac Industries increased from INR 1 million (US$ 22,000) pre-TRIPS to INR 1.65 million (US$ 36,000) post-TRIPS.[8] Interestingly, the average R&D Investment of Titan Industries Ltd. (which was unaffected by TRIPS) also increased from INR 21.5 million (US$ 477,000) pre-TRIPS to INR 32.25 million (US$ 717,000) post-TRIPS, an increase of approximately 50 percent. That increase was, to a large part, due to an expansion into the prescription eyewear business.[9] In contrast, the average industry R&D for firms unconnected with the pharmaceutical/chemical industry before and after the introduction of TRIPS was INR 2.84 million (US$ 63,000) and 3.93 million respectively (US$ 87,000), increasing only by approximately 38 percent.

We further investigate *how* firms respond and change behaviour as a result of these network externalities. We identify two types of effects: an *innovation effect*, whereby board interlocks foster the transmission of genuinely new knowledge that allows a firm to conduct new research, and a *strategic effect*, that arises from a situation in which a firm decides to patent an existing invention because of information on the value of patenting obtained through a board interlock. It is important to note that both effects are different manifestations of the same underlying mechanism: information transmission through interlocking boards of directors.

Our evidence suggests that board interlocks enable an innovation effect on R&D - the exchange of information and knowledge across firms allows firms to be more innovative (invest more in R&D). We distinguish between two types of R&D. R&D expenditure on the current account (current R&D) refers to short-term spending that is fully expensed in the fiscal period in which it is incurred. R&D expenditure is incurred on the capital account (capital R&D) when a firm buys fixed assets related to R&D, that can be capitalized and amortized over their useful life. We document that the innovation effect on R&D shows up largely in its effect on current short-term expenditure while capital R&D is largely unaffected. This is not entirely surprising. While a board member might suggest a change in

[8]The average is reported over two years. Therefore the 'pre-TRIPS' value is the average R&D expenditure over the two years prior to the TRIPS reform and the 'post-TRIPS' value is the average R&D expenditure over the two years after the TRIPS reform.

[9]See Guha, R., 2006, "India Titan Indus MD: Expect FY Net +40% at INR1.03B", *Dow Jones Newswires*, 21 November 2006. The firm already manufactured watches, jewelry, and sunglasses but planned to launch a new prescription eye-wear business with pilot stores in Bangalore, Chennai, and Nagpur.

emphasis on innovation, it is unlikely (as in the Titan Industries example) that a firm will change its entire pattern of innovation in the short term. Hence, board suggestions are more likely to show up in the firm's current R&D expenses which includes short-term exploratory R&D expenses designed to examine the viability of a new technology, rather than in capital R&D which is likely to be set by the firm management for the longer term.

The effect of network size on patenting, in contrast, is driven by a strategic effect - board interlocks make the firm more aware of its strategic position and hence motivate the firm to protect its inventions strategically through formal intellectual property in the form of patents. We show that the strategic effect operates through a different channel from the innovation effect, specifically, firms increase their patenting propensity as a response to an increase in their corporate network, while holding the amount of innovation constant. Interestingly, this relation applies to patent filings abroad, that is, Indian companies are more likely to file a patent abroad on an invention that is already patented domestically as a reaction to information obtained through new directors appointed to the company's board. This indicates an economically significant change in firms' intellectual property strategy as a result of new information transmitted by interlocked directors.

This paper contributes to two areas of finance. First, it contributes to a growing body of literature that examines the relationship between innovation and inter-firm alliances that occur through strategic partnerships, business groups, or corporate networks. Firms that share an alliance through a strategic partnership are more likely to share technological knowledge, thereby increasing their propensity to patent. Using patent citation counts as a proxy for the flow of technological knowledge, Gomes-Casseres, Hagedoorn, and Jaffe (2006), show that pairwise citations are strongly increasing in the alliance association intensity of the two firms; being greatest for firms with alliances of extended duration, multiple alliances, and alliances with equity or joint R&D components. The results are at best, however, suggestive of knowledge sharing, since the results could, in part, reflect reverse causality – in this case, a tendency for higher citation rates between two firms to lead them to form an alliance, a possibility acknowledged by the authors. Business group affiliations are also a strong predictor for firm innovative activity (Chang, Chung, and Mahmood 2006; Belenzon and Berkovitz 2010). While prior literature has stressed that the existence of group internal capital markets and knowledge spillovers are likely to be instrumental for a firm's propensity to patent, Belenzon and Berkovitz (2010) argue that knowledge spillovers themselves are not the main driver of innovation in business groups because firms within the same business group often do not share the same research focus. In a similar vein, Chang et al. (2006) find that groups with diverse research interests might actually inhibit individual affiliates' innovativeness. Our analysis contributes to this literature by providing evidence of non-market based interactions between firms induced through the sharing of board members across companies.

Second, our paper contributes to the literature on the impact of networks in different types of organizations. Hochberg, Ljungqvist, and Lu (2007) show that venture capital (VC) firms with influential network positions have significantly better fund performance, as measured by the proportion of investments that are successfully exited through an IPO or sale to another company. Cohen, Frazzini, and Malloy (2008b) analyze connections between mutual fund managers and corporate board members via shared education networks and find that portfolio managers place larger bets on connected firms and perform significantly better on these holdings relative to their unconnected holdings. Cohen, Frazzini, and Malloy (2008a) show that analysts provide superior stock recommendations when they have an educational link to the company's executives. In our paper, we identify a specific channel through which board networks add to shareholder value in publicly listed firms by transmitting information on innovative activities across firms and thereby influencing innovative activities and intellectual property protection strategies.

The rest of the paper is organized as follows: Section 2 discusses the identification strategy and the empirical framework. The data used is described in Section 3. Section 4 discusses the results and Section 5 concludes.

2 Empirical Approach

In our analysis, we identify the effect of network size on firms' R&D investment and patenting behavior by exploiting exogenous variation in firms' network size induced by a recent corporate governance reform in India. The reform required firms in our sample to adjust, among other things, their board structure. The resulting board restructuring entailed a substantial change in firms' network size.[10] Identifying variation comes from firms subject to the reform that fell short of the board size require-

[10] We note that there could nevertheless also be increases in the network size of firms not affected by the reform because some of their directors would have been hired as board members in companies below the threshold as a result of the reform. In this sense, our first stage computes an 'intention to treat' estimate rather than the actual treatment impact. See also Section 2.2, and footnote 16.

ment when the reform was introduced and their comparison with firms that already satisfied the new board size requirement when the reform was introduced. This means that we effectively rely on a differences-in-differences framework, comparing firms that fell short of the board restructuring requirement and those that did not at the time of the reform. Additional variation is obtained from the staged introduction of the reform over a period of three years in which different types of firms were required to comply earlier than others.

2.1 Corporate Governance Reforms - Clause 49A

In 2001, on the recommendation of the Kumar Mangalam Committee, the Security and Exchange Board of India (SEBI) proposed several amendments to the Clause 49 of the Listing Agreement. To be effective from 1 January 2006, it required a range of corporate governance related reforms to be undertaken with a particular emphasis on board size and structure. First, it required changes in the composition of the board of directors as follows: the board was required to have a specific combination of executive and non-executive directors with not less than 50 percent of the board of directors consisting of non-executive directors. Second, it also required changes with regard to the share of independent directors on a board.[11] The share would depend on whether the chairman was an executive or non-executive. In case of a non-executive chairman, at least one-third of the board was required to consist of independent directors and in case of an executive chairman, at least half of the board was required to consist of independent directors (SEBI, Clause 49A). The reforms also laid down the code of conduct for directors, board procedures, compensation to non-executive directors, audit committee requirements and whistle blower policy regulations. For example, the reform mandated that a director sit on no more than fifteen firms' boards at a time (more details are provided in Appendix A).

Importantly, SEBI also required schedule-wise implementation of the reforms. Specifically, group *A* firms on the BSE were expected to comply by March 31, 2001 (i.e. from fiscal year 2001 onward). These are generally the largest corporations in the Indian economy. Group *B* firms or firms that had a paid up share capital of at least INR 10 crores (approximately US$ 2.22 million) or net worth of

[11] An 'independent director' is defined as one who "[...] apart from receiving director's remuneration, does not have any material pecuniary relationships or transactions with the company, its promoters, its senior management, its holding company, its subsidiaries and associated companies; is not related to promoters or management at the board level or at one level below the board; has not been an executive of the company in the immediately preceding three financial years; is not a partner or an executive of the statutory audit firm or the internal audit firm that is associated with the company, and has not been a partner or an executive of any such firm for the last three years" (SEBI, Clause 49A, p1).

more than INR 25 crores (US$ 5.55 million) at any time in the company's history, were expected to comply by March 31, 2002 (i.e. from fiscal year 2002 onward). Finally, other firms with paid up share capital of at least INR 3 crores (US$ 0.66 million) were expected to comply by March 31, 2003 (i.e. from fiscal year 2003 onward). Listed companies with a paid up share capital of below INR 3 crore or net worth of INR 25 crores or less at any time in the history of the entity were not required to comply with these measures.

2.2 Network Size

Our primary variable of interest is the network size of a firm. The network size is the composition of a firm's corporate network affiliations created through interlocking boards of directors.[12] An interlocking directorate occurs when a director of the board of one firm also sits on the board of another company. A firm can have one or more directors who sit on the boards of other firms. While firms can also be connected through social ties between directors based on shared educational background of executives or past employment of employees, our data does not allow us to identify such potential connections. Therefore, in our paper, we focus specifically on inter-company relationships through interlocked boards, that is, in our analysis, two firms share a direct link in the corporate network if they share a director.[13]

Our objective is to examine whether firms with larger networks file more patents and have larger R&D expenses.[14] The equation of interest measuring the effect of network size on patent counts or R&D expenditure therefore is:

$$y_{it} = \alpha + \beta N_{it} + \gamma x_{it} + \mu_i + \gamma_t + u_{it} \tag{1}$$

where y_{it} is one of three separate firm-specific outcome measures – patent counts (domestic as

[12]In our analysis, we distinguish these board interlock connections from links that result from business group affiliations.

[13]Throughout the paper we measure inter-firm network connections between all listed companies in India. However, the directors of each listed company also serve on boards of non-listed companies. Since these non-listed companies are not part of the sample, our measure of network size omits linkages between listed and non-listed companies, thereby inducing a potential measurement error. However, the extent of this measurement error is likely to be negligible, since the bulk of non-listed companies belong to industries that neither conduct much formal R&D nor rely on patents to protect their inventions. Including these companies is likely only to serve to inflate our network size measure, without adding any value to the informational content contained in the networks.

[14]We concentrate on network size rather than structure as our primary determinant of a firm's innovative behavior. This is justified by a high correlation of network size and network structure in our data. For example, in our sample, the correlation coefficient of a firm's betweenness centrality and network size is 0.84, where the betweenness centrality is a measure of how important a node is in terms of connecting other nodes.

well as international patents), R&D expenditure, and the ratio of patent counts to R&D (as a measure of patenting propensity). N_{it} is the network size of firm i in time period t, μ_i represents firm fixed effects and γ_t includes time dummies.

There are several empirical issues with this analysis. First, the Ordinary Least Squares (OLS) estimate of network size in Equation (1) will be inconsistent if network size is endogenous. Second, better performing and more innovative firms may strategically place themselves in a network, leading to reverse causality issues. Third, more centrally located firms may also be more likely to perceive the need to use patents strategically. Finally, unobserved factors that affect both network size and output measures could cause an omitted variable bias.

2.2.1 IV Approach

To circumvent the endogeneity problem, we use the exogenous variation brought about by the corporate governance reform described in Section 2.1. As mentioned previously, the reforms prescribed minimum percentages of non-executive directors for all publicly listed firms: "The board of directors of the company shall have an optimum combination of executive and non-executive directors with not less than fifty percent of the board of directors comprising of non-executive directors." (SEBI Clause 49, 2003).[15] Firms that did not comply with this requirement faced significant penalties and possible de-listing. As described above, the reforms were phased in between 2001 and 2003. An issue of concern is that the timing of compliance was defined by firm size. As a result, the average size of firms that have to comply earlier is larger than that of firms that had to comply later. We account for this in two ways: we use firm fixed effects to absorb the initial size differences in firms and the change in total assets for any given firm over time to address later changes in size differences.

To create an instrument that is uncorrelated with the second stage error but is able to predict network size, we make use of the board structure of firms before the reform period. The corporate governance measures required only some firms to restructure their board. Those eligible firms which did not meet the board structure requirement before the reform period were likely to employ more

[15] Clause 49 also called for an increase in the proportion of independent directors comprising the board. However, we are unable to calculate the exact proportion of independent directors on the board of each listed firm for several reasons. First, PROWESS does not have a comprehensive classification of directors into independent and non-independent directors. Second, even when such an indicator exists, it is not entirely reliable primarily because the definition of an 'independent director' is ambiguous. Finally, the indicator of whether the chairman of the board is an executive or non-executive is also ridden with extensive missing values. For these reasons, we choose to calculate a more basic requirement of board composition that the firm had to comply with – the proportion of executive to non-executive directors – for which we have complete data.

independent or non-executive directors and thereby increase interlinkages. Therefore we are able to control for the direct effect of the treatment and exploit the additional variation due to the interaction of the treatment and whether a firm was required to restructure its board of directors to estimate network size. The instrument is then given by the interaction term, $(B_i \times R_t)$, where B_i takes the value one if a firm's board structure did not meet the requirements and it was eligible as set out in Clause 49, and R_t is a dummy variable taking the value one for years where the reform was applicable, which varies by groups A, B, and C. This gives us the following estimation equations:

$$N_{it} = \alpha^{ITT}(B_i \times R_t) + \gamma^f x_{it} + \mu_i^f + \varsigma^f t + \eta_{it} \quad (2)$$

$$y_{it} = \beta \widehat{N}_{it} + \gamma x_{it} + \mu_i + \varsigma t + u_{it} \quad (3)$$

Equation 2 predicts corporate network size N of firm i at time t using the interaction term $(B_i \times R_t)$, firm-specific characteristics x_{it} including the proportion of non-executives in a given year, as well as firm fixed effects and time dummies. The firm-fixed effects capture the systematic time-invariant difference between the different set of companies eligible for the reform (B_i). The proportion of non-executives in a given year and time dummies explicitly capture the direct effect of board composition (related to the executive/non-executive ratio) and the corporate governance reform on firm patenting and R&D (R_t). As a result, we are able to control separately for the direct effects that each of the two terms in our instrument could have on the dependent variable and exploit only their interactive effect. We also control for the total board size of each firm. Equation 3 uses predicted network size $\hat{N}$ to estimate the impact of corporate network size on firms' patent filings or R&D, y_{it}. The exclusion restriction is $(B_i \times R_t)$, which represents the identifying instrument.The ITT superscript emphasizes the fact that this specification estimates the intent-to-treat (ITT) effect, that is, the effect of eligibility for treatment on outcomes after the reforms came into effect.[16]

[16]In medical terminology, "Intent-to-treat" is a strategy for the analysis of randomised controlled trials that compares patients in the groups to which they were originally randomly assigned. This is generally interpreted as including all patients, regardless of whether they actually satisfied the entry criteria, the treatment actually received, and subsequent withdrawal or deviation from the protocol. For example, in a trial comparing medical and surgical treatment for a particular illness, some patients allocated to surgical intervention might die before being operated on. If these deaths are not attributed to surgical intervention using an intention to treat analysis, surgery would seem to have a falsely low mortality. In addition, ITT analysis also allows for non-compliance and deviations from policy by firms (see for example, Hollis and Campbell (1999)).

2.2.2 Regression Discontinuity Approach

The instrumental variable approach discussed so far rests on the the assumption that variation in network size comes exclusively from board adjustments made by 'eligible' (i.e. companies to which the reform applies and that have a proportion of independent directors below the threshold mandated by the reforms *before* the reforms become effective) companies *after* the reforms became effective. One potential concern with this approach is that companies that are below and above the critical threshold *before* the reforms, differ in terms of time-varying unobservable characteristics (for example, in the quality of their R&D) that are correlated with network size and not accounted for by covariates x_{it} and firm-fixed effects μ_i.[17]

In this sub-section, we describe an alternative identification strategy that relaxes the unconfoundedness assumption required to identify the network effect from differences in the changes of network size between companies below and above the threshold, before the reforms become effective. We use a regression discontinuity approach that identifies the effect of the reforms on network size from comparisons between companies arbitrarily close to the critical board composition threshold. This approach has also the advantage that we can account directly for the criteria that jointly determine whether firms were expected to adjust their board structure: the net worth of the firm and the proportion of non-executives in their board at a given point of time.[18] Treatment is therefore defined based on the interactions of these two threshold variables, that is, the interaction of whether a firm was below the requirement in terms of board composition and whether it was eligible for compliance in terms of its net worth.

We denote $PROP_{it}$ as the observed proportion of non-executives on firm i's board (normalized to zero at the threshold equal to 0.5) at time t. As in the IV approach in Equation 2, the binary variable B_{it} indicates whether the firm was below the required board composition criteria and was therefore required to adjust. Note that in contrast to Equation 2, B_{it} is now time-varying.[19] The

[17] Coles et al. (2008), for example, show that board size, which is correlated with network size, is associated with various time-varying firm and board characteristics.

[18] As mentioned in Section 2.1, firms with a paid-up share capital of of at least INR 3 crores (US$ 0.66 million), i.e. groups A, B, and C, were expected to comply by March 31, 2003. In addition, only those firms with a below 50 percent proportion of non-executives in their boards were required to adjust.

[19] A potential concern with allowing B_{it} to vary over time is that firms might bunch around the threshold. In view of this, as a robustness check, we also estimate the regression discontinuity specification keeping B_i fixed at its pre-reform value as in the IV approach. This means that we only estimate the network size effects for firms near the threshold before the reform became effective. Our results are very similar to those reported in Table 6, the main difference being that they are estimated over a smaller sample of firms.

second continuous forcing variable is denoted as SC_i, which is the amount of paid up share capital for a given firm i. We create two binary variables, SC_i^A and SC_i^B which indicate whether a firm was classified as a group A or a group B firm[20]. In addition to the binary instruments, $(B_{it} \times SC_i^A)$ and $(B_{it} \times SC_i^B)$, we include each variable on its own in the instrument set. As in Cellini et al. (2010), we keep all companies in the sample but account for the distance to the treatment thresholds by including a set of polynomials for the 'running' threshold variables, net worth (SC_i) and proportion of non-executives ($PROP_{it}$), as well as polynomials of their joint effect ($PROP_{it} \times NW_i$). The first-stage therefore is specified as:

$$\begin{aligned} N_{it} = \ & \alpha_1^{ITT}(B_{it} \times SC_i^A) + \alpha_2^{ITT}(B_{it} \times SC_i^B) + \alpha_3^{ITT}(PROP_{it}) + \alpha_4^{ITT}(SC_i^A) + \alpha_5^{ITT}(SC_i^B) \\ & + f_B(PROP_{it}, \gamma_1) + f_{SC}(SC_{it}, \gamma_2) + f_{B,SC}(PROP_{it} \times SC_i, \gamma_3) + \varsigma t + \eta_{it} \end{aligned} \tag{4}$$

Again, the ITT superscript highlights the fact that this specification estimates the intent-to-treat (ITT) effect.[21]

3 Data

We use several sources of data. We obtain firm level accounting data from the PROWESS database provided by the Center for Monitoring of the Indian Economy (CMIE). International patent filings (both US and European) come from the European Patent Office's (EPO) Worldwide Patent Statistical Database (PATSTAT). Domestic patent filings come from EKASWA, the Indian Patent Office, and BigPatents India.

3.1 Firm-level Data

For our analysis we use data for *all* publicly listed companies in India – including the Bombay Stock Exchange (BSE) and the National Stock Exchange (NSE) – during the period 2000-2007. The data come from PROWESS, which is a firm-level database provided by the Centre for Monitoring Indian

[20]The reason for not using Group C firms as an instrument is that there is a potential concern about their innovative capacity. This strategy, in fact, aids our identification because, in general, we find that Group C firms innovate far less but witness a higher increase in their network and board size which contributes to extra noise in our estimation.

[21]For more discussion on the distinction between ITT and treatment on the treated (TOT) effects within this regression discontinuity framework, see Khanna and Palepu (2000).

Economy (CMIE). For each publicly traded Indian firm, we obtain detailed information on accounting balance sheets, financial statements, industry information, group affiliation for each firm, corporate ownership data and share prices. The database also includes information on R&D. This is measured as the total outlay of the company on research and development during the year on its current and capital account. R&D expenditure is incurred on the capital account when a firm buys fixed assets related to R&D, that can be capitalized and amortized over their useful life. In contrast, R&D expenditure on the current account refers to short-term spending that is fully expensed in the fiscal period in which it is incurred. Note that we obtain an unbalanced panel as the annual reports for few companies are missing in some time periods.

As in other papers (Khanna and Palepu 2000; Bertrand, Mehta, and Mullainathan 2002), we rely on CMIE to classify our sample firms into business and non-business group firms, and to classify group firms into specific group affiliation which is the result of a 'continuous monitoring of company announcements and a qualitative understanding of the groupwise behavior of individual companies' (Prowess Users' Manual, v.2, p.4). This information allows us to disentangle network effects from business-group effects. For identifying industry affiliation, we use information on the principal line of activity of the firm and use the National Industry Classification (NIC) code accorded to them. The Prowess data also provides detailed information on the directors serving on the board of each firm, along with information on the number of board meetings attended, salary, directors' fee etc. The listing of these directors is unique within each time period and we undertake an exhaustive matching exercise to ensure uniqueness across time periods.[22]

We use a parsimonious specification in our analysis to control for other exogenous firm characteristics. Specifically, we include total book value of assets (in logs) and total exports divided by sales of a company (in logs). We also include a company's board size to account for scale effects. Moreover, we construct an industry-level patenting propensity variable (number of patents divided by R&D investment) that captures time-varying industry-specific patent-related effects (Hall and Ziedonis 2001). Finally, though firm fixed effects are likely to absorb business group effects, we also capture potentially time-varying resource sharing effects within business groups through a separate variable that measures patenting propensities within business groups. All control variables are lagged by one year. Table 1 shows the corresponding descriptive statistics for the firms included in

[22] We only observe the list of board members at the beginning of each fiscal year, which means changes in board structure are measured on an annual (fiscal year) basis.

our regression analysis. In addition, Table 2 offers a breakdown of average R&D expenditure, patent counts, network size, and company characteristics across the different eligible company categories before and after the reforms became effective. The table also distinguishes between companies that were below and those that were above the required board composition threshold. The table shows that the network size changed significantly across all company categories regardless of whether a company was below or above the threshold. R&D expenditure also changed significantly following the reform – but only changes for companies above the threshold are statistically significant. There is less evidence for significant changes in patent counts.

3.2 Patent Data

For international patent filings with the US Patent and Trademark Office (USPTO) and the European Patent Office (EPO), we rely on EPO's PATSTAT database version April 2010. We extract from PATSTAT patents filed by Indian residents at the USPTO and the EPO.[23] While the USPTO and EPO data can be expected to be complete, there is serious under-reporting in PATSTAT of Indian domestic patent filings with the Indian Patent Office (CGPDT). We therefore rely instead on three other databases. The electronic patent search facility available on CGPDT's website *iPairs* provides information on published patents only from 2005 onwards.[24] For patent filings before 2005, we rely on the *EKASWA* database assembled by the Patent Facilitating Centre (PFC) of the Indian Department of Science and Technology. *EKASWA* contains all domestic patents published between January 1995 and early 2005.[25] In addition, we use the online portal *BigPatents India*.[26] In principle, *BigPatents India* provides the same information as *iPairs* from the patent office journal. However, since the two databases do not completely overlap, we complement the official data sources using *BigPatents India*.

Our analysis focuses on the application date of a patent.[27] However, patent data are only visible after a patent has been published which implies that although we use the application date, our sample of patents is limited to patents that have been published. Given the usual 18-month delay

[23] This includes patents filed with the World Intellectual Property Organization (WIPO) through the PCT route.

[24] The search facility also provides information on granted patents before 2005. This, however, misses any patent that was not granted. Given our research objective, we are interested in any patent filing independently of whether it was eventually granted.

[25] The data in *EKASWA* come from the Patent Office Gazette, which was published only in print format. The Gazette was replaced in 2005 by the Patent Journal, which is published both in print and electronic formats.

[26] http://india.bigpatents.org

[27] Note that our accounting data are reported by fiscal year, that is, from 1st April in a given calendar year to 31st March of the subsequent calendar year. Therefore we also allocate patents accordingly into fiscal year intervals based on their precise application date.

between application and publication date at USPTO, EPO and CGPDT,[28] this implies that we only have patent data until March 2009 at best. This leads us to limit the period of analysis to 2000-2008 in order to avoid missing data problems stemming from the reporting delay between application and publication date of a patent.[29] Due to the absence of a unique identifier shared by the firm-level and patent data, the main problem in constructing our dataset consists in matching patents to firms. To match assignee names to company names, we rely on a combination of an automated matching algorithm and extensive manual checking of the (un)matched data. More specifically, we first 'clean' and standardize firm names in both datasets to a maximum possible to avoid the occurrence of 'false negatives', that is patents/firms that should have matched but did not do so. In a second step, we match cleaned and standardized assignee and company names, where strings have to coincide perfectly for names to match. In addition, we checked *all* unmatched and matched firms manually. We also cross-check matched domestic Indian, USPTO, and EPO patents using 'equivalents', that is, we verify whether for example a given matched USPTO patent has an EPO equivalent for the same innovation and whether this EPO equivalent had been matched (and vice versa).[30] Section C of the appendix explains the matching algorithm and outcome in more detail. Section B of the appendix contains a detailed description of the Indian patent system. That section describes the changes in the Indian patent system over the past two decades. The most significant change was triggered by India's WTO accession in 1995 which led to the granting of patents on pharmaceutical and chemical products (compounds) from 2005 onward. Since this change falls into our sample period, we discuss potential implications for our analysis below (see Section 4.2).

For our analysis, we keep only companies in industries with at least one patent filing during the sample period. This is done to ensure that companies' inventions represent patent-eligible subject matter and patenting as a means of appropriating returns to innovating is a relevant option for companies. Figure 1 shows the distribution of patenting firms across industries. The figure reveals a

[28] The USPTO may not automatically publish an application 18 months after its priority date if requested by the applicant provided *the invention disclosed in the application has not and will not be the subject of an application filed in another country or under a multilateral international agreement, that requires publication of applications eighteen months after filing* (35 U.S.C. 122(b) and §1.211). Hence, if an Indian applicant patents an invention with the USPTO that he also patents with EPO and/or CGPDT, the application will be published within 18 months.

[29] Though PATSTAT reports patent data from 1990 and EKWASA from 1995, firm-level information is only available from 1999. Since we arrange the data by fiscal year, the time series used in our analysis extends into 2008 (until the 31st March) despite the fact that we only use firm-level data up to 2007.

[30] For EPO and USPTO patents, our definition of equivalents follows Martinez (2010). Since we do not have priority information for the domestic Indian patents, we retrieve Indian equivalents of matched EPO and USPTO from EPO's Espacenet.

substantial amount of heterogeneity across sectors. On average, there are 7.8 percent of patenting firms in the sample, with the share of patenting firms varying between less than 1 percent in the services sector and around 22 percent in the transport equipment industry, which consists largely of the automobile sector. The pharmaceutical and chemical industry is the second most patent active industry with a share of around 18 percent of patenting companies.

4 Results

4.1 Network Size

We first examine the impact of corporate network size on firms' innovative efforts, i.e., the *innovation effect*. Panel A of Table 4 reports both OLS and IV results when using total R&D expenditure as the dependent variable. All specifications include firm and time fixed effects. Standard errors are clustered at the company-level. Column (1) reports the OLS fixed effects results ignoring the potential endogeneity of the network size measure. The resulting coefficient associated with network size is positive, but small in magnitude. Economically, the coefficient implies that one additional board interlock is associated with an increase of 0.2 percent in R&D expenditure. Columns (2)-(5) show the results from exploiting our identification strategy, that is, when we instrument network size through the differences-in-differences specification. First-stage results for predicting a firm's network size are shown in Column (2). The interaction term is statistically significant at the 1 percent level and has a negative sign, that is, a negative impact on the number of interlocks. A priori, the direction of the effect of a change in board composition is ambiguous since the reform only required a change in composition and no adjustment in board size (which we account for directly). Hence, accounting for board size among the conditioning variables, we find that the effect of increasing the share of non-executive directors on network size was *negative*.

To explain this result, in Panel B of Table 4, we present summary statistics on changes in network dynamics for the above and below threshold firms around the reform period. Column (1) splits the firm-year sample by reform/non-reform and above and below threshold firms. We find that the reform increased the total network size of both types of firms but the increase was more pronounced for the firms above the threshold. This post-reform difference, 2.174, is statistically significant at the 1 percent level, explaining the negative effect of our instrument on network size in the first stage. To explore this further, we divide the network size gain for each firm in three parts: the network gained on behalf of directors newly appointed (*hires*), the network lost on behalf of exiting directors (*fires*) and finally the network gained on behalf of sitting directors (*remaining*). We then compute the average post and pre reform differential between networks size gains for each of these subcomponents. We find that the average gain in network size to firms from their hires of new directors net of their fires of old directors are similar across the two types of firms (above and below threshold) and not statistically significant. However, we find a positive and significant difference in the network gain from remaining/sitting directors between above and below threshold firms. To understand this effect, we note the general equilibrium implications of the reform's effect. While the reform induced a shift in network size for those firms that were required to comply (below threshold firms), it also caused a shift in the network size of those that were not required to (above threshold firms). This is because the directors of above threshold firms are likely to have been recruited by below threshold firms, thereby increasing the network size of above threshold firms, possibly more than that of below threshold firms. To summarize, the network size gain to firms from *existing* directors' network is higher for above threshold firms compared to below threshold firms. This explains our first stage estimates and in particular, why the increase in total network size was more pronounced for above threshold firms post-reform.

Returning to Table 4 Panel A, columns (3), (4), and (5) report our IV second stage results using our instrumented network size from column (2). In column (3), the coefficient on instrumented network size increases to 0.009, but is no longer statistically significantly different from zero. Table 2 indicated that changes in R&D expenditure following the reforms differ considerably between current and capital R&D expenditure. Columns (4) and (5) of Table 4 where we break total R&D expenditure into current and capital expenditure confirm this for our multivariate regressions.[31]

We find a statistically significant effect of network size only on current but not on capital R&D expenditure. This finding is most likely explained by a firm's ability to adjust one type of R&D expenditure more easily than the other in response to information obtained through shared directors.

The comparison of the OLS and IV estimates of network size implies that the effect of network size on innovation is biased downward when we ignore the endogeneity of network size (the 'naive' OLS estimate on current R&D expenditure is 0.002 whereas the IV estimate is 0.014). This raises

[31]The OLS estimates for network size on current and capital R&D expenditure are 0.0019 and 0.0010 respectively. Both estimates are statistically significant at the 1% level.

the additional concern that network size effects simply pick up differences in firm types between the below- and above-threshold firms. For instance, a below-threshold firm may strategically choose to add directors by linking only with high R&D investing firms above the threshold. This would imply that any effect of network size on outcomes would be conflated with such selection effects. Panel C of Table 4 examines this issue by comparing the average characteristics of companies whose directors were hired post-reform by companies that were either below or above the threshold. If the effect is driven by selection, one would expect below-threshold companies to systematically hire directors from different 'types' of companies than above-threshold companies. The table shows that none of the differences in average characteristics is statistically significant at 10 percent. This means that there is little evidence to suggest the effects are driven by unobserved differences across firm types. The downward bias of the OLS estimates is more likely to result from the endogeneity of network size itself, that is, companies' endogenous choice of the directors that they hire as a response to the reforms.

Table 5 reports the results for our second dependent variable, the firms' patent filings. As in Table 4, we report both the OLS results from a 'naive' specification ignoring network endogeneity and from the IV specification discussed in Section 2.2. A comparison of the naive and IV specifications reveals again a severe downward bias in the coefficient associated with network size if we ignore network size endogeneity. The coefficient from the IV specification shown in Column (3) is 0.09 (while the OLS coefficient is 0.01), which implies that a one standard deviation increase in network size leads to an increase of 0.25 standard deviations in the number of patent applications. Columns (4) and (5) break this effect up into international (EPO and USPTO) and domestic patent filings. The results indicate that only the effect on filings abroad is statistically significant, with a coefficient of 0.03. The coefficient associated with domestic filings is not statistically different from zero.[32]

This may suggest that firms respond to new information obtained from inter-company networks by filings for patent protection abroad. The results for the other covariates do not differ significantly from the R&D specification shown in Table 4.

Although Panel C of Table 4 does not indicate any statistically significant differences in observable characteristics between companies below and above the critical threshold before the reforms, as discussed in Section 2.2.2, there is still the possibility that they differ in unobservables that are

[32]The OLS estimates for network size on domestic and international patent counts are 0.0115 and 0.0017 respectively. The estimates are statistically significant at the 10% and 5% level for domestic and international patent counts respectively.

not absorbed by firm-level fixed effects. To address this concern, Table 6 shows the estimates obtained from using the regression discontinuity approach specified in Equation (4). The results are qualitatively very similar to the results reported from the IV approach in Panel A of Table 4 and Table 5. When relying on the regression discontinuity approach, both current R&D expenditure and the coefficient on total R&D expenditure are statistically significant.[33] While the coefficients on R&D increase in magnitude when using the regression discontinuity approach (for current R&D, the effect increases for a 1 unit increase in network size from 1.4 to 2.7 percent), estimates for the regressions with patent filings as the dependent variable are very similar in magnitude to the IV results. For total patent counts, the estimate is 0.08 (for IV 0.09), for domestic filings 0.05 (for IV 0.06), and for international filings 0.03 (for IV 0.035). Interestingly, we now also find a statistically significant coefficient on domestic patent filings.

To summarize our results so far, increases in network size appear to be positively related to changes in current R&D expenditure. In addition, firms appear to increase patent filings abroad whereas our results for domestic filings are less clear. We analyze these effects in more detail in the next sections.

4.2 Pharmaceutical/Chemical Sector

As discussed in Section B of the appendix, the India Patents Act of 1970 prohibited the granting of pharmaceutical and chemical product patents. India's WTO accession in 1995 forced the government to re-align its patent system with TRIPS, which meant among other things an extension of the statutory patent life and the patentability of pharmaceutical and chemical product inventions. While patent applications on pharmaceutical and chemical compounds could be filed beginning January 1995, these applications were only examined and granted from January 2005 onward.

Chaudhuri, Goldberg, and Jia (2006), among others, argue that prohibiting patentability of pharmaceutical and chemical products had a major positive impact on the development of a domestic pharmaceutical industry in India. This suggests that the re-introduction of pharmaceutical product patents could have also impacted the domestic pharmaceutical industry and hence affected R&D expenditure and patent filings. Arora, Branstetter, and Chatterjee (2011) find an increase in private

[33] The estimates on capital R&D expenditure are also positive and statistically significant. However, we place more emphasis on the IV results than the RDD results because the latter are likely to be driven by variation *across* only a subset of companies around the threshold. The results from the IV approach come from the entire sample of companies and also use variation over time *within* the cross-section firms.

returns to R&D conducted by a sample of publicly traded Indian pharmaceutical companies during the post-WTO accession period. Several other articles (e.g. Kale and Little 2007) and press reports (Economist June 16 2005; Financial Times April 17 2008) pointed to evidence of the emergence of a "research-driven" Indian pharmaceutical industry following WTO accession. Yet, evidence by Arora, Branstetter, Chatterjee, and Saggi (2009) shows that this "research-driven" Indian pharmaceutical industry still focuses largely on process innovations, where the increase in research activity and patenting observed since 2005 is attributed to an overwhelming extent to increased sales of generics and bulk drugs in Western markets, especially the U.S. This suggests that while there was an increase in R&D and patent filings post-2005, these patents and R&D are largely concerned with the same type of research, i.e., processes and production methods as before 2005.

In our setting, a primary concern is that the fundamental change in the Indian patent system for pharmaceutical and chemical product patents that became effective in 2005, induced a common correlated shock specific to pharmaceutical and chemical companies in our sample. Since the corporate governance reform that we exploit to identify the network size effect predates the granting of pharmaceutical and chemical patents, it is reasonable to assume that it is uncorrelated with the change in the patent system. Nevertheless, to investigate the presence of a pharma/chemicals-specific shock, we include in our specification in Equation (3) an indicator variable that assumes the value one for the pharmaceutical and chemical sector from 2005 onward. This pharma/chemicals-specific trend break captures a potential common correlated effect induced by the granting of pharmaceutical and chemical product patents beginning 2005. Our results shown in Table 7, Column (1), indicate no statistically significant association between the pharma/chemicals shock and network size, as would be expected. In contrast, the results shown in Column (2) suggest that the introduction of pharmaceutical and chemical product patents has had a strong, statistically significant, positive effect on pharmaceutical and chemical companies' R&D expenditure as well as patent filings. The indicator variable for the pharma/chemicals-specific trend break has a coefficient of 0.158 in Column (2), implying that the introduction of pharmaceutical and chemical product patents increased R&D expenditure by almost 16 percent. The aggregate patent count (Indian, EPO, and USPTO) increased by over 1.5 patents post-2005. Columns (4) and (5) suggest that the effect was more pronounced for Indian patents than for EPO and USPTO patents, which would be expected given that pharmaceutical and chemical products were patentable abroad before 2005. The coefficients associated with network size remain positive and statistically significant, but fall slightly in magnitude relative to Tables 4 and 5. All other results remain largely unaffected by the inclusion of the interaction term capturing the regime change in pharmaceutical and chemical patents.

4.3 Unboxing Network Size: Peer Effects in Research Activity

The change in the patent system that affected pharmaceutical and chemical companies in particular is also useful in directly analyzing the driving forces behind the observed positive effect of network size on R&D spending and patenting. Specifically, we investigate whether the average 'network' R&D spending and patenting affects a company's own R&D spending and patenting.

The identification of peer effects encounters well known problems laid out in Manski (1993). In general, three effects need to be distinguished in the analysis of peer effects. The first type of effects are endogenous effects which arise from a firm's propensity to behave in some way as a function of the behavior of the group. The second are so-called contextual effects which represent the propensity of a firm to behave in some way as a function of the exogenous characteristics of its peer group. The third type are correlated effects which arise due to factors that are common amongst firms belonging to the same group, which compel them to behave in a similar manner. Our main focus lies in estimating endogenous peer effects, owing to its capacity of generating social multiplier effects.[34] We therefore exploit the joint interaction effect of the board restructuring reform and the TRIPS patent reform to identify the endogenous peer effect i.e. average network patenting and R&D. Our instrument exploits two different sources of variation: cross sectional variation from differing board restructuring requirements of firms and time series variation from the TRIPS reform that affected patent and R&D behavior for pharmaceutical and chemical firms in particular.

Our results from the previous sections indicate that the board restructuring reform decreases the network size of those firms that were required to comply with the reforms, i.e. firms that were below the threshold. We, therefore, expect that firms that were above the threshold and were not required to comply with the reform have, on average, a larger network size. To ease interpretation, we modify our board restructuring reform instrument and define a dummy variable for firms that were above the threshold (not required to comply) and interact it with the pharmaceutical/chemicals

[34]For a more general overview of the many problems encountered in estimating peer effects and different methods proposed for their estimation, see Epple and Romano (2011) for a comprehensive recent review of the social interactions literature.

shock indicator. Our instrument for peer effects is thus composed of two parts.

- ***Reform***×***Above Threshold***: The first reduced form effect comes from the board restructuring reform that, *potentially*, increases the proportion of pharmaceutical and chemical firms in the network of above-threshold firms, by increasing their network size compared to below-threshold firms.[35]

- ***TRIPS***: The second effect comes from the TRIPS reforms where we expect to see an increase in the average R&D and patenting of pharmaceutical and chemical firms.

The interaction of these two effects, the dummy variable ***Reform***×***Above Threshold***×***TRIPS***, therefore induces a positive upward shift in the average R&D and patenting of network firms engaged in pharmaceutical and chemical activities. For identification, we use this instrument and estimate peer effects on a sub-sample of *non-pharmaceutical/chemical firms* (approximately 90 percent of the sample) that were *not* directly affected by the TRIPS reform regarding patentability of pharmaceutical/chemical compounds. Our identification strategy relies, therefore, only on exogenous variation that induced a shift in the patenting and R&D behavior, for a subset of networked firms, without affecting the target firm itself. We note that our IV estimates have a LATE (Local Average Treatment Effect) interpretation since our instrument is able to identify the requisite variation only for firms that link to at least one pharmaceutical company.

Table 8 shows the corresponding results. Column (1) shows the first stage results for the specification using R&D spending as the dependent variable. The specification includes the same variables as the main specification shown in in Table 5 with the addition of network-based variables, that is, averages across corporate networks.[36] We also control for potential sources of correlated effects by controlling for average industry and business group R&D and patenting. The number of observations is lower than in preceding tables because the sample excludes pharmaceutical and chemical companies. The first stage results show that the board restructuring reform and the TRIPS patent reform interaction is positive and statistically significant as expected. The second-stage results reveal a positive and statistically significant coefficient on other firms' R&D spending within a company's

[35]We remain agnostic about the actual proportion of pharmaceutical firms in each firms network. As a result we only expect that some pharmaceutical firms are added to the network as a result of the reform but do not include or impose this selection criteria to be a part of our instrument.

[36]Note that we do not include a network size variable because this is implicitly accounted for in our peer effect variable i.e. average network peer R&D or patents. Including a network size variable separately would induce collinearity issues causing our instrument to fail the rank condition.

corporate network on its own R&D spending. This indicates that the positive effect found in Table 5 can be explained – at least partially – by positive peer effects, that is, R&D spending by companies within corporate networks is positively correlated. Columns (3) and (4) show that the effect only exists for current R&D spending, which is consistent with Table 5. Column (6) of Table 8 shows that there are no such network effects for patenting (this result continues to hold if we split patents into national and international filings). As the patent counts for non-pharmaceutical/chemical firms are low, we lack enough variation to obtain precise estimates for peer effects in patenting behavior, at least in the short run. The lack of an immediate response to peer activity in the short run can also be inferred from the result that only the current expenditure component of R&D is affected due to the network. Capital expenditure, which tends to be inelastic and is relatively difficult to adjust in the short run, is unaffected by average (capital) R&D of peer firms. Our results therefore reflect only the short-run effects of networked peer firms on own firm research activity.

4.4 Distinguishing the Innovation Effect from the Strategic Effect

The positive effect of an increase in network size on a firm's number of patent filings can theoretically be explained by both an innovation and a strategic effect. The innovation effect arises from the transmission of genuinely new knowledge that allows a firm to conduct new research or modify existing processes/products in a way that leads to patentable outcomes. The strategic effect, in contrast, arises from a situation in which a firm decides to patent an existing invention because of information obtained through a board interlock. This may happen, for example, if a shared director informs a board about the patenting activities of another company on whose board he also sits. There is also a third possibility: the board interlock may provide strategic information that leads to innovation. This situation could arise if, for example, a shared director informs the board of the strategic importance of conducting a certain type of R&D (or on a certain technology). This type of "strategic innovation" effect is observationally equivalent to the pure innovation effect because it also implies that the company does not patent an existing invention. These innovation effects, however, can be distinguished from the strategic effect because the strategic effect implies that the company already possesses a patentable invention but had previously chosen not to patent it.

Our results shown in Table 4 using a firm's R&D expenditure as the dependent variable suggest that board interlocks and hence network size impact a firm's innovative activity. This means that these results provide evidence in favor of an innovation effect – a result reinforced by our finding that the positive effect applies mainly to current expenditure on R&D. The results in Table 5, however, are more difficult to interpret because, in principle, innovation as well as strategic effects could give rise to the observed positive impact of network size on patent filings. One way to interpret our results is to acknowledge the implicit timing assumptions made in our analysis. Since we look at contemporaneous effects of network size on patenting, it is difficult to imagine that firms are able to respond so quickly to the transmission of new knowledge to lead to an immediate filing of a patent on a new invention. The contemporaneous link between the increased flow of information and patenting is more likely to be the result of the patenting of existing inventions. The finding in Table 5 that the change in network size affected only international patent filings reinforces this notion. To investigate this issue further, we analyze patenting along two additional dimensions. First, we estimate the impact of network size on patenting propensities directly. Second, we exploit information on patent families to gauge the effect on a firm's propensity to file an additional patent on an existing invention.

Table 9 reports results when using the ratio of patent counts to R&D – a firm's patenting propensity – as the dependent variable. The results in Column (2) from our differences-in-differences specification indicate a positive, albeit statistically insignificant effect of network size on a firm's overall patenting propensity. Columns (3) and (4) break this up again into domestic and international filings. The estimates confirm the results shown in Table 5. The change in network size affects only the propensity to file a patent abroad. The corresponding coefficient of 0.009 implies that an increase of one standard deviation in network size increases patent propensity by 0.07 standard deviations. This suggests that an increase in corporate network links through interlocking boards impacts on patenting by raising a firm's international patenting propensity, which reflects a strategic effect.

To investigate specifically whether information transmission through board interlocks triggers firms to patent existing inventions, we construct an indicator variable that is equal to one if a firm files a patent application that is an equivalent of a previously filed patent application.[37] For example, the indicator is equal to one if a firm files in 2003 a patent application with the EPO for which it has already filed a domestic patent application in 2002 with the Indian patent office. This indicates that

[37]Because patents are national rights, to obtain patent protection, patents have to be obtained in each jurisdiction separately in which patent protection is sought. Patents on the same invention in different jurisdictions are referred to as equivalents.

the firm is not filing a patent on a new invention, but merely decides to also patent a given invention in another jurisdiction. We add this variable to our specification and interact it with our measure of network size. The corresponding results are shown in Table 10. In Column (1), when we add the 'previous equivalent' dummy variable to our specification, we find the corresponding estimated coefficient to be large, negative, and statistically significant. As would be expected, if a firm has already patented a given invention, the likelihood of patenting is reduced considerably. Columns (2)-(4) show results for total, domestic and foreign patent filings when we interact the equivalent dummy variable with our measure for network size. This specification tests whether the increase in network size impacts a firm's patent filing behavior due to strategic considerations which is reflected in the firm's decision to patent an existing invention (as indicated by the previous patent filing). The interaction term is positive across all three specifications, but statistically significant only in the case of foreign filings. This indicates that an increase in network size indeed leads to the filing of a foreign patent on an existing invention.

Overall, our results paint a consistent picture. They suggest that the positive effect of network size on foreign patenting found in Table 5 is mainly the result of a firm's strategic response to new information. Hence, these results indicate the presence of a *strategic effect* from interlocking boards of directors on patenting behavior.

5 Conclusions

In this paper, we investigate if increases in the size of board networks increase innovative behavior among firms. We find that they do. To tackle the endogeneity inherent in determining firms' network sizes, we exploit two natural experiments. The first is a corporate governance reform introduced between 2001 and 2003 that forced a subset of Indian firms to restructure their boards of directors. The restructuring led to a substantial change in the size of corporate networks. The comparison of companies forced to restructure with companies that were not, allows us to identify the effect of network size on R&D spending and patenting. The second is a change in the patent law for Indian pharmaceutical and chemical companies that allowed firms to patent pharmaceutical and chemical product innovations. We use this change as an instrument for changes in R&D and patenting behavior among non-pharmaceutical firms.

We find that current R&D expenditure is significantly positively related to changes in the size of the firm's network of directors. We interpret this as an *innovation effect* that arises as a consequence of the information transmitted via shared directors. Our analysis based on the policy change related to pharmaceutical and chemical patents shows that the innovation effect is driven by peer effects, i.e., a positive association of R&D spending by companies within corporate networks. We also find that the number of patent filings increases significantly following a board restructuring. We show that this is most likely the result of a *strategic effect*, that is, firms file more patents on existing inventions after obtaining information of strategic value through directors that sit on other (potentially) competing firms' boards of directors. Interestingly, this strategic effect impacts Indian companies' decisions to file patents abroad (at the EPO and USPTO). In other words, an exogenous increase in network size significantly increases the probability that the firm extends the geographical scope of patent protection by filing a foreign patent application on an existing invention.

Overall, we find substantial non-market externalities on research and patenting activity between firms, induced through the sharing of board members across companies. Our evidence suggests that shared directors serve as a channel for the transmission of information across companies which impacts both their innovative as well as strategic patenting behavior. Future research could investigate the impact of these innovation and strategic effects on company performance.

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Appendix

A Corporate Governance Reforms

All reform eligible companies were required to submit a quarterly compliance report to the stock exchanges within 15 days from the close of the quarter according to the format shown in Figure 2. This format includes all provisions as mandated by the reform; compliance status on each item had be verified and signed either by the Compliance Officer or the Chief Executive Officer of the company.

B Indian Patent System

This section provides some background information on the Indian patent system, which is relevant for the interpretation of our results. Since India's independence from the British Empire in 1947, the Indian patent system has undergone two sets of radical reforms in opposite directions. The first dramatic change to the patent system was enacted in 1970 with the India Patents Act, which came in force in April 1972. The principal change introduced by the Patents Act was to deny patentability to pharmaceutical and chemical *products*. Yet, pharmaceutical and chemical *process* inventions remained patentable, although their patent life was restricted to 7 years counting from filing date whereas the life of any other patent was 14 years. Moreover, only a single process or method was patentable for a specific drug. The 1970 Patent Act also enacted provisions that allowed compulsory licensing of pharmaceutical drug related process patents.

When India entered the World Trade Organization (WTO) in January 1995, it also adopted the Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement. Under TRIPS, India was required to fundamentally change its intellectual property system in the opposite direction of what the 1970 Patent Act had achieved. This change was carried out through three major amendments to the 1970 Patents Act. The most significant change required by TRIPS was the recognition of the patentability of pharmaceutical and chemical product patents, although India was allowed to postpone their granting until January 2005. However, according to TRIPS regulations, patentees were allowed to file pharmaceutical and chemical product patent applications during this 10-year transition period through a so-called 'pipeline' system. While operating since January 1995, the pipeline system was formally enacted only by the 1999 Patents (Amendment) Act.[a] In 2002, India brought its legal system further inline with TRIPS requirements through the the 2002 Patents (Amendment) Act, which among other things, introduced a 20-year patent validity term and allowed patents to cover multiple processes/methods. In its 2002 Patents (Amendment) Act, India formally recognized its accession in 1998 to the Paris Convention, which stipulates national treatment for foreign assignees and their right to use 'priority' derived from patent filings in other Paris Convention countries within a 12-months period preceding filing in India. It also formally recognized India's accession in 1998 to the Patent Cooperation Treaty (PCT), which allows filing for patent protection through the World Intellectual Property Organization (WIPO).[b] Finally, the 2005 Patents (Amendment) Act allowed the granting of pharmaceutical and chemical product patents.

C MATCHING OF PATENT DATA

The original PROWESS dataset contains 25,404 unique firm names. After cleaning and standardizing, we have 25,319 unique firm names which are matched with the assignee names of CGPDT, USPTO, and EPO patents. EPO and USPTO patent data come from EPO's PATSTAT database whereas filings with the Indian patent office come from three sources as explained in Section 3.2 in the main text: *iPairs*, *EKASWA*, and *BigPatents India*. The USPTO, and EPO patent files contain 1,431, and 705 unique assignee names of Indian residents respectively. The assignees contain a large range of different assignee types, including private individuals, universities, and research institutes. We attempt to keep only private and state-owned companies because none of the other assignee types is contained in PROWESS. After dropping any assignees that are not private or state-owned companies, cleaning/standardizing assignee names, and keeping only patents applied for between 1990-2008, we obtain 375 and 314 unique names in the USPTO and EPO patent files, respectively. These assignees correspond to 1,489 and 1,717 patent filings respectively. Table 3 shows the resulting matching rates. The Indian patent data was compiled in different ways. *EKASWA* provided us with the complete set

[a]Applicants were allowed to file patent applications, but they would not be examined and published until the end of the 10-year transition period. The main advantages of filing for a patent through the pipeline system was that patent examination was executed in order of filing date once the transition period had ended and that prior art was evaluated according to the available information at the priority date of the patent (which could have coincided with the application date). Mueller (2006) reports that 8,926 patent applications were filed during the 10-year transition period through the pipeline system.

[b]This meant applicants could file for patent protection in India by filing a PCT application with WIPO and designating India for the national phase of the filing. Similarly, Indian nationals are able to file patent applications with WIPO and designate India as well as other PCT members for entry into the national phase.

of assignees and patents which we matched to our sample of PROWESS firms. *iPairs* and *BigPatents India* provide online access to the data. We downloaded all assignee names from *iPairs* and matched them to our sample of firms and then downloaded only those patents for the matched *iPairs* assignee names. When downloading the patent data, we checked that at least one inventor on a given patent document indicates an Indian residence. This increases the likelihood that a given patent was filed by the headquarter/subsidiary in India. We also trawled *BigPatents India* for companies in our PROWESS dataset and obtained additional patents in this way. Moreover, we cross-checked our USPTO, EPO and Indian patent data using equivalents to ensure that the match is consistent. This implies that if, for example, a matched USPTO patent has an Indian equivalent, we verify that we also matched the Indian equivalent to its owner.

Table 1: Summary Statistics

This table reports summary statistics of variables used in our regressions for the full sample of firms over the years 2000-2007. The sample consists of 11,358 firm-year observations. Patent data are extracted from USPTO, EPO (*PATSTAT* version April 2010), *EKASWA*, *iPairs*, and *BigPatents India*. All firm level variables are obtained from the PROWESS database. Only firms listed on the BSE are part of the sample. We report the mean, standard deviation and the range (minimum, maximum) of each variable.

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
R&D (log)	11,358	0.201	0.639	-0.605	6.681
Current R&D	11,358	0.167	0.566	0	6.189
Capital R&D	11,358	0.078	0.387	0	6.458
Total Patent Count	11,358	0.389	5.114	0	240
Domestic Patent Count	11,358	0.281	3.887	0	202
International Patent Count	11,358	0.108	1.713	0	72
Patent Propensity (total)	11,358	0.130	1.304	0	46.415
Patent Propensity (domestic filings)	11,358	0.097	1.067	0	46.415
Patent Propensity (int. filings)	11,358	0.033	0.458	0	22.896
Network Size	11,358	11.700	14.196	0	114
Assets (log)	11,358	3.998	2.169	-4.605	12.020
Exports by sales (log)	11,358	0.099	0.201	-0.009	6.917
Board size	11,358	7.909	3.484	1	31
Industry Patenting Propensity	11,358	0.115	0.211	0	0.836
Business Group Patenting Propensity	11,358	0.057	0.608	0	46.415

Table 2: Summary Statistics by category – before and after the reform

This table reports summary statistics of variables used in our regressions for the full sample of firms over the years 2000-2007. We report the mean of each variable and distinguish among 3 dimensions: (1) company Group A, Group B, and Group C, (2) companies below and above the required threshold introduced by the reform, as well as (3) before and after the reform took effect. Patent data are extracted from USPTO, EPO (*PATSTAT* version April 2010), *EKASWA*, *iPairs*, and *BigPatents India*. All firm level variables are obtained from the PROWESS database. Only firms listed on the BSE are part of the sample.

	Above required proportion			Below required proportion		
	Before reform **Mean**	After reform **Mean**	Difference t-statistic	Before reform **Mean**	After reform **Mean**	Difference t-statistic
Group A						
R&D (log)	0.414	0.612	1.960	0.356	0.445	0.790
Current R&D	0.331	0.529	2.157	0.309	0.379	0.693
Capital R&D	0.181	0.242	0.975	0.113	0.200	1.151
Total Patent Count	0.338	1.216	1.398	0.469	2.072	0.971
Network Size	18.154	24.607	3.980	12.897	20.038	3.624
Assets (log)	6.296	6.545	1.702	5.870	6.033	0.704
Board size	10.704	11.309	1.878	9.469	9.777	0.769
Group B						
R&D (log)	0.203	0.308	2.566	0.163	0.197	0.849
Current R&D	0.137	0.263	3.498	0.121	0.162	1.135
Capital R&D	0.093	0.111	0.721	0.070	0.081	0.436
Total Patent Count	0.372	0.378	0.043	0.114	0.239	1.156
Network Size	11.711	14.769	3.542	9.032	10.684	2.002
Assets (log)	4.665	4.757	0.958	4.463	4.234	-1.958
Board size	8.570	8.867	1.562	7.975	7.647	-1.568
Group C						
R&D (log)	0.127	0.129	0.118	0.035	0.028	-1.117
Current R&D	0.098	0.104	0.383	0.022	0.021	-0.451
Capital R&D	0.042	0.044	0.188	0.012	0.009	-1.060
Total Patent Count	0.020	0.077	1.480	0.007	0.009	0.321
Network Size	7.048	9.914	6.792	3.596	6.237	7.828
Assets (log)	3.554	3.469	-1.368	2.799	2.737	-1.008
Board size	7.399	7.690	2.674	5.598	6.370	7.987

Table 3: Matched dataset

This table shows the matching rates between the various patent databases. USPTO and EPO patents are extracted from *PATSTAT* version April 2010. CGPDT patents are from *EKASWA*, *iPairs*, and *BigPatents India*. The original PROWESS dataset contains 25,404 unique firm names. After cleaning and standardizing, we have 25,319 unique firm names which are matched with the assignee names of CGPDT, USPTO, and EPO patents. The USPTO, and EPO patent files contain 1,431, and 705 unique assignee names of Indian residents respectively. After dropping any assignees that are not private or state-owned companies, cleaning/standardizing assignee names, and keeping only patents applied for between 1990-2008, we obtain 375 and 314 unique names in the USPTO and EPO patent files, respectively. These assignees correspond to 1,489 and 1,717 patent filings respectively.

	Assignee names				**Patents**		
	Raw Data	Cleaned Data	# Matched	Match Success	# Patents	# Matched	Match Success
iPairs	105,731	97,540	218	0.22%		6,851	
BigPatents India			70			219	
EKASWA	13,842	11,260	369	3.28%	21,595	2,769	12.82%
CGPDT			506			9,485	
USPTO	1,431	375	173	46.13%	1,976	1,489	75.35%
EPO	705	314	168	53.50%	4,110	1,717	41.78%

Table 4: Network Size Effects: R&D

This table reports results on the effect of network size on firm research and development expenditure. The sample consists of 11,358 firm-year observations from 2000 to 2007. The first panel (Panel A) reports the results from our main regression specification (Equation 2 & 3) and the last two panels (Panel B & C, contd. on next page) provide descriptives that help explain results from the first stage of the IV regression. **Panel A**: Column (1) reports results from an OLS regression; the dependent variable for this model is total research and development expenditure (in logs). Column (2) reports the first stage of the IV regression where the dependent variable is total network size. Column (3) reports the corresponding second stage; the dependent variable is total research and development expenditure (in logs). Columns (4) and (5) report IV second stage results for different components of research and development expenditure: current R&D (Column (4)) and capital R&D (Column (5)). All control variables are lagged by one year and include the following: Proportion Non-Executives is the proportion of Non-Executive directors in the board; Assets in logs is total book value of assets; Network Size measures the number of direct links i.e. the number of other firms with whom a given firm shares common directors; Aggr. Industry Patents is the aggregate patents count normalized by R&D expenditure within each industry; Aggr. Business Group Patents is the aggregate patents count normalized by R&D expenditure within each business group. Standard errors clustered by firm are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

PANEL A

	Dependent Variable:				
	(1) R&D (OLS)	(2) Network Size (IV I)	(3) R&D (IV II)	(4) Current R&D (IV II)	(5) Capital R&D (IV II)
Network Size	0.002**		0.009	0.014**	0.002
	(0.001)		(0.006)	(0.005)	(0.004)
Reform×Eligible Below Threshold		-2.680***			
		(0.555)			
Proportion Non-Executive	-0.048*	2.912***	-0.065**	-0.071**	-0.012
	(0.027)	(0.762)	(0.031)	(0.029)	(0.023)
Log Assets	0.025***	0.541***	0.021***	0.011*	0.014***
	(0.006)	(0.128)	(0.007)	(0.006)	(0.005)
Log Exports/Sales	0.056*	0.672	0.051*	0.044*	0.026
	(0.030)	(0.495)	(0.028)	(0.024)	(0.017)
Aggr. Industry Patents	-0.016	-0.940**	-0.009	-0.031	0.005
	(0.029)	(0.475)	(0.029)	(0.027)	(0.022)
Aggr. Business Group Patents	0.005	-0.082	0.005	0.009*	0.002
	(0.005)	(0.066)	(0.004)	(0.005)	(0.003)
Board size	0.003	0.435***	0.000	-0.002	0.001
	(0.003)	(0.061)	(0.004)	(0.003)	(0.002)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
N	11,358	11,358	11,358	11,358	11,358
First-Stage F			23.27	23.27	23.27

Table 4 (contd.): Network Size Effects: R&D

Panels B & C of the table report additional results corresponding to the first stage statistics. **Panel B**: This panel reports the differences in network size between above and below threshold companies. The sample in Column (1) consists of 3,711 above-threshold and 1,813 below-threshold firm-year observations. The sample in Column (2) consists of 9,447 above-threshold and 4,052 below-threshold firm-year observations. The sample in Column (3) consists of 1,799 above-threshold and 858 below-threshold firms. Columns (1) and (2) report pre and post differences in total network size between above and below threshold companies. Column (3) reports the difference in network size between the post and pre reform periods. This is reported in two ways: the gain in network size to firms from their hires of new directors net of their fires of old directors (*Network hires - Network fires*); and the gain in network size to firms from those directors that remained in the company (*Network remaining*). ** Differences are statistically significant at 1%. **Panel C**: This panel reports the average firm-level characteristics for firms appointing new directors in the post-reform period. The sample consists of 1,177 above-threshold and 560 below-threshold firms. Average firm characteristics were calculated by averaging the firm characteristics over each firm hiring a new director excluding the target firm. Figures reported in the table are sample means of these averages across below/above threshold companies and for all years. None of the differences are statistically significant at the 10% level. Mean difference are statistically evaluated using both parametric (t-test) and non-parametric (Wilcoxon-Mann-Whitney) tests.

PANEL B

	Total Network Size		Network gain from	
			hires - fires	remaining
	Pre Reform (1)	Post reform (2)	(Post-Pre) difference (3)	
Above Threshold	7.138	12.268	0.091	4.082
Below Threshold	5.649	10.094	0.117	3.368
Difference	1.489**	2.174**	-0.026	0.714**

PANEL C

	Average firm-level characteristics for firms appointing directors post-reform			
	Below required proportion	Above required proportion	Difference	
			t-statistic	Wilcoxon z-statistic
R&D (log)	0.222	0.251	1.196	1.474
Current R&D	0.180	0.198	0.838	1.600
Capital R&D	0.074	0.088	1.128	1.228
Total Patent Count	0.226	0.230	0.048	-0.275
Domestic Patent Count	0.189	0.196	-0.114	-0.634
International Patent Count	0.029	0.040	0.418	-0.563
Patent Propensity (total)	0.150	0.222	0.775	-0.266
Patent Propensity (domestic)	0.142	0.209	0.727	-0.780
Patent Propensity (int.)	0.007	0.012	0.707	0.785
Assets (log)	4.486	4.453	-0.384	0.182
Exports by sales (log)	0.104	0.094	-0.905	0.562

Table 5: Network Size Effects: Patent counts

This table reports results on the effect of network size on firm patents. The sample consists of 11,358 firm-year observations from 2000 to 2007. Column (1) reports results from an OLS regression; the dependent variable for this model is the total number of patents (international and domestic). Column (2) reports the first stage of the IV regression where the dependent variable is total network size. Column (3) reports the corresponding second stage; the dependent variable for this model is the total number of patents (international and domestic). Columns (4) and (5) report IV second stage results for different types of patents: patents filed domestically (Column (4)) and patents filed internationally (Column (5)). All control variables are lagged by one year and include the following: Proportion Non-Executive is the proportion of Non-Executive directors in the board; Assets in logs is total book value of assets; Network Size measures the number of direct links i.e. the number of other firms with whom a given firm shares common directors; Aggr. Industry Patents is the aggregate patents count normalized by R&D expenditure within each industry; Aggr. Business Group Patents is the aggregate patents count normalized by R&D expenditure within each business group. Standard errors clustered by firm are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

	Dependent Variable:				
	(1) Patent Count (OLS)	(2) Network Size (IV I)	(3) Patent Count (IV II)	(4) India Patent (IV II)	(5) Int. Patent (IV II)
Network Size	0.013*		0.093*	0.058	0.035**
	(0.007)		(0.055)	(0.039)	(0.017)
Reform×Eligible Below Threshold		-2.680***			
		(0.555)			
Proportion Non-Executive	-0.148	2.912***	-0.328	-0.250	-0.078
	(0.197)	(0.762)	(0.230)	(0.191)	(0.066)
Log Assets	0.064**	0.541***	0.019	0.011	0.009
	(0.031)	(0.128)	(0.037)	(0.034)	(0.011)
Log Exports/Sales	0.309	0.672	0.250	0.184	0.066
	(0.193)	(0.495)	(0.165)	(0.127)	(0.052)
Aggr. Industry Patents	-0.840**	-0.940**	-0.762**	-0.435*	-0.327**
	(0.416)	(0.475)	(0.378)	(0.261)	(0.143)
Aggr. Business Group Patents	0.106*	-0.082	0.111*	0.084*	0.027*
	(0.060)	(0.066)	(0.060)	(0.049)	(0.016)
Board size	-0.001	0.435***	-0.036	-0.021	-0.016
	(0.015)	(0.061)	(0.030)	(0.022)	(0.011)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
N	11,358	11,358	11,358	11,358	11,358
First-Stage F			23.27	23.27	23.27

Table 6: Network Size Effects: Regression Discontinuity Design

This table reports results on the effect of network size on research and development expenditure and patent filings. The sample consists of 13,773 and 3,030 firm-year observations from 2000 to 2007 in Panel A and B respectively. The first panel (Panel A) reports results from the pooled regression discontinuity (RD) specification (Equation 4) for the entire sample of firms while the second panel (Panel B) reports results for a subsample of firms within a narrowly defined bandwidth (firms whose proportion of non-executives lies between 0.35 and 0.65). All columns of both panels report results from the RD specification with flexible polynomials of the two thresholds i.e. proportion of non-executives, net-worth of firms and their interactions. We condition on time fixed effects and use as instruments the treatment variables as defined by the thresholds: being below the required proportion of non-executives, being eligible for the reform based on net-worth, and their interaction. The dependent variable for the columns are: total research and development expenditure (in logs) (Column (1)), total current research and development expenditure (in logs) (Column (2)), total number of patents (Column (3)), patents filed domestically (Column (4)) and patents filed internationally (Column (5)). Standard errors clustered by firm are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

PANEL A: Full Sample

	Dependent Variable:				
	(1)	(2)	(3)	(4)	(5)
	R&D	Current R&D	Patent Count	India Patent	Int. Pat
Network Size	0.030***	0.027***	0.083**	0.053*	0.030**
	(0.005)	(0.004)	(0.042)	(0.029)	(0.015)
Polynomials Net Worth (Eligibility)	Yes	Yes	Yes	Yes	Yes
Polynomials Prop. NE (Requirement)	Yes	Yes	Yes	Yes	Yes
Polynomials Eligibility × Requirement	Yes	Yes	Yes	Yes	Yes
N	13,773	13,773	13,773	13,773	13,773
First-Stage F	24.577	24.577	24.577	24.577	24.577

PANEL B: Narrow Bandwidth

	Dependent Variable:				
	(1)	(2)	(3)	(4)	(5)
	R&D	Current R&D	Patent Count	India Patent	Int. Pat
Network Size	0.043***	0.038***	0.137*	0.110*	0.027*
	(0.009)	(0.008)	(0.073)	(0.060)	(0.016)
Polynomials of Net Worth (Eligibility)	Yes	Yes	Yes	Yes	Yes
Polynomials of Prop. NE (Requirement)	Yes	Yes	Yes	Yes	Yes
Polynomials of Eligibility × Requirement	Yes	Yes	Yes	Yes	Yes
N	3,030	3,030	3,030	3,030	3,030
First-Stage F	11.901	11.901	11.901	11.901	11.901

Table 7: Pharmaceutical/chemical Shock

This table reports results on the effect of network size on firm research and development expenditure and patents accounting for the TRIPS agreement. The sample consists of 11,358 firm-year observations from 2000 to 2007. All specifications in this table control for the effect of the TRIPS reform on patenting. Column (1) reports the first stage of the IV regression where the dependent variable is total network size. Column (2) reports the corresponding second stage; the dependent variable for this model is the total expenditure on R&D (in logs). Columns (3), (4) and (5) report IV second stage results for: total number of patents (Column (3)), patents filed domestically (Column (4)) and patents filed internationally (Column (5)). All control variables are lagged by one year and include the following: Proportion Non-Executive is the proportion of Non-Executive directors in the board; Assets in logs is total book value of assets; Network Size measures the number of direct links i.e. the number of other firms with whom a given firm shares common directors; Aggr. Industry Patents is the aggregate patents count normalized by R&D expenditure within each industry; Aggr. Business Group Patents is the aggregate patents count normalized by R&D expenditure within each business group. Standard errors clustered by firm are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

	Dependent Variable:				
	(1) Network Size (IV1)	(2) R&D (IV II)	(3) Patent Count (IV II)	(4) India Patent (IV II)	(5) Int. Patent (IV II)
Network Size		0.002**	0.091*	0.056	0.034**
		(0.0009)	(0.054)	(0.039)	(0.017)
Reform×Eligible Below Threshold	-2.678***				
	(0.555)				
Proportion Non-Executive	2.920***	-0.044*	-0.289	-0.223	-0.065
	(0.763)	(0.025)	(0.223)	(0.185)	(0.063)
Pharma×TRIPS	0.349	0.158***	1.447**	0.977*	0.469***
	(0.653)	(0.041)	(0.679)	(0.591)	(0.162)
Log Assets	0.541***	0.025***	0.020	0.011	0.009
	(0.128)	(0.006)	(0.037)	(0.034)	(0.011)
Log Exports/Sales	0.666	0.053*	0.227	0.169	0.058
	(0.493)	(0.028)	(0.149)	(0.116)	(0.048)
Aggr. Industry Patents	-0.879**	0.011	-0.512*	-0.266	-0.246**
	(0.442)	(0.027)	(0.292)	(0.209)	(0.123)
Aggr. Business Group Patents	-0.082	0.005	0.112*	0.085*	0.027*
	(0.065)	(0.004)	(0.057)	(0.047)	(0.014)
Board size	0.435	0.003	-0.037	-0.021	-0.016
	(0.061)	(0.002)	(0.031)	(0.022)	(0.011)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes
N	11,358	11,358	11,358	11,358	11,358
First-Stage F			23.21	23.21	23.21

Table 8: Peer Effects: R&D and patents

This table reports results on peer effects in patenting and R&D from board interlocking networks size. The sample consists of 10,087 firm-year observations from 2000 to 2007. All specifications in this table report estimates for peer effects from networks resulting from board interlocks. Column (1) reports the first stage of the IV regression where the dependent variable is the average R&D (in logs) expenditure of networked/peer firms. Column (2) reports the corresponding second stage; the dependent variable for this model is the total expenditure on R&D (in logs). Columns (3) and (4) report IV second stage results for different components of research and development expenditure: current R&D (Column (3)) and capital R&D (Column (4)). Column (5) reports the first stage of the IV regression where the dependent variable is the average patents (international and domestic) of networked/peer firms. Column (6) reports the corresponding second stage; the dependent variable for this model is the total number of patents (international and domestic). All control variables are lagged by one year and include the following: Assets in logs is total book value of assets; Network Size measures the number of direct links i.e. the number of other firms with whom a given firm shares common directors; Aggr. Industry Patents is the aggregate patents count normalized by R&D expenditure within each industry; Aggr. Business Group Patents is the aggregate patents count normalized by R&D expenditure within each business group. Heteroscedasticity robust standard errors are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

	Dependent Variable:					
	(1) Network R&D (IV I)	(2) R&D (IV II)	(3) Current R&D (IV II)	(4) Capital R&D (IV II)	(5) Network Patents (IV I)	(6) Patent Count (IV II)
Network Firms' R&D		1.009*	1.051**	0.404		
		(0.565)	(0.489)	(0.772)		
Network Firms' Patents						-0.638
						(0.654)
Reform×Eligible Above Threshold ×TRIPS	0.034**				-0.145	
	(0.014)				(0.123)	
Log Assets	0.005	0.009	0.004	0.007	0.030	0.033
	(0.006)	(0.008)	(0.008)	(0.007)	(0.031)	(0.030)
Log Exports/Sales	0.039**	-0.007	0.004	0.001	0.131	0.171
	(0.019)	(0.027)	(0.018)	(0.022)	(0.082)	(0.130)
Board size	0.001	0.002	0.003	-0.0001	-0.003	-0.001
	(0.002)	(0.003)	(0.003)	(0.002)	(0.018)	(0.017)
Network Log Assets	0.024***	-0.024*	-0.014	-0.004	0.175***	0.119
	(0.005)	(0.015)	(0.009)	(0.006)	(0.052)	(0.114)
Network Log Exports/Sales	0.030	-0.047	-0.039	-0.019	0.320**	0.248
	(0.019)	(0.027)	(0.024)	(0.021)	(0.140)	(0.214)
Network Board size	-0.002	0.001	-0.002	0.0003	-0.069***	-0.049
	(0.002)	(0.003)	(0.003)	(0.001)	(0.023)	(0.045)
Aggr. Industry Patents	0.026	0.041	0.034	0.048**	-0.053	-0.016
	(0.027)	(0.038)	(0.030)	(0.023)	(0.217)	(0.146)
Aggr. Business Group Patents	0.001	-0.001	0.004	-0.004	0.040	0.038
	(0.002)	(0.006)	(0.003)	(0.005)	(0.029)	(0.039)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	10,087	10,087	10,087	10,087	10,087	10,087
First-Stage F		5.92	7.686	3.511		1.382

Table 9: Network Size Effects: Patent Propensity

This table reports results on the effect of network size on the firm's ratio of total patent counts to R&D. The sample consists of 11,358 firm-year observations from 2000 to 2007. Column (1) reports results from an OLS regression; the dependent variable for this model is the ratio of total patent counts to R&D. Column (2) reports the IV second stage results (the first stage results are similar to Column (2) of Table 4); the dependent variable for this model is the ratio of total patent counts to R&D. Columns (3) and (4) report IV second stage results for different types of patent ratios: ratio of domestic patents to R&D (Column (3)) and ratio of international patents to R&D (Column (4)). All control variables are lagged by one year and include the following: Proportion Non-Executive is the proportion of Non-Executive directors in the board; Assets in logs is total book value of assets; Network Size measures the number of direct links i.e. the number of other firms with whom a given firm shares common directors; Aggr. Industry Patents is the aggregate patents count normalized by R&D expenditure within each industry; Aggr. Business Group Patents is the aggregate patents count normalized by R&D expenditure within each business group. Standard errors clustered by firm are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

	Dependent Variable:			
	(1)	(2)	(3)	(4)
	$\frac{\text{Patent Count}}{\text{R\&D}}$		$\frac{\text{India Patent Count}}{\text{R\&D}}$	$\frac{\text{Int. Patent Count}}{\text{R\&D}}$
	(OLS)	(IV II)	(IV II)	(IV II)
Network Size	0.002	0.014	0.006	0.009**
	(0.003)	(0.018)	(0.017)	(0.004)
Proportion Non-Executive	0.048	0.021	0.063	-0.042
	(0.083)	(0.105)	(0.098)	0.027
Log Assets	0.011	0.004	0.001	0.003
	(0.012)	(0.016)	(0.016)	(0.003)
Log Exports/Sales	0.095	0.087	0.051	0.036
	(0.063)	(0.059)	(0.045)	(0.026)
Aggr. Industry Patents	-0.015	-0.003	0.067	-0.071***
	(0.184)	(0.173)	(0.165)	(0.024)
Aggr. Business Group Patents	0.077**	0.078**	0.064*	0.014
	(0.039)	(0.039)	(0.038)	(0.016)
Board size	-0.007	-0.012	-0.008	-0.004
	(0.008)	(0.008)	(0.007)	0.003
Time Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
N	11,358	11,358	11,358	11,358
First-Stage F		23.28	23.28	23.28

Table 10: Innovation vs. Strategic Effect – Equivalents

This table reports results on the effect of network size on patent equivalents. The sample consists of 11,358 firm-year observations from 2000 to 2007. Column (1) reports results from an OLS regression; the dependent variable for this model is the total patent equivalents. We define a patent equivalent as an indicator variable that is equal to one if a firm files a patent application that is an equivalent of a previously filed patent application. Column (2) reports the IV second stage results (the first stage results are similar to Column (2) of Table 4); the dependent variable for this model is the total patent equivalents. Columns (3) and (4) report IV second stage results for different types of patent equivalents: domestic patent equivalents (Column (3)) and international patent equivalents (Column (4)). All control variables are lagged by one year and include the following: Proportion Non-Executive is the proportion of Non-Executive directors in the board; Assets in logs is total book value of assets; Network Size measures the number of direct links i.e. the number of other firms with whom a given firm shares common directors; Aggr. Industry Patents is the aggregate patents count normalized by R&D expenditure within each industry; Aggr. Business Group Patents is the aggregate patents count normalized by R&D expenditure within each business group. Standard errors clustered by firm are reported in parentheses. * indicates significance at 10%; ** at 5%; *** at 1%.

	Dependent Variable:			
	(1)	(2)	(3)	(4)
	Patent Equivalents		India Patent Equivalents	Int. Patent Equivalents
	(OLS)	(IV II)	(IV II)	(IV II)
Network Size	0.013*	0.013*	0.011*	0.001
	(0.007)	(0.007)	(0.006)	(0.002)
Previous Equivalent (PQ)	-10.943**	-19.176	-12.104	-7.072*
	(5.427)	(13.215)	(10.290)	(4.230)
PQ×Network Size		0.438	0.149	0.288*
		(0.487)	(0.402)	(0.152)
Proportion Non-Executive	-0.113	-0.084	-0.105	0.022
	(0.194)	(0.196)	(0.160)	(0.061)
Log Assets	0.059*	0.057*	0.032	0.025
	(0.030)	(0.031)	(0.029)	(0.009)
Log Exports/Sales	0.286	0.273	0.195	0.078
	(0.179)	(0.168)	(0.128)	(0.053)
Aggr. Industry Patents	-0.777**	-0.698**	-0.399*	-0.299**
	(0.388)	(0.307)	(0.223)	(0.116)
Aggr. Business Group Patents	0.115*	0.116*	0.089	0.027
	(0.069)	(0.071)	(0.057)	(0.018)
Board size	-0.002	-0.003	-0.001	-0.002
	(0.015)	(0.015)	(0.013)	(0.006)
Time Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
N	11,358	11,358	11,358	11,358

Figure 1: Patenting by industry

This figure shows the distribution of patenting firms (the share of firms in each industry with at least one patent) across industries over the period 2000-2007. For our analysis, we keep only companies in industries with at least one patent filing during the sample period. This is done to ensure that companies' inventions represent patent eligible subject matter and patenting as a means of appropriating returns to innovating is a relevant option for companies.

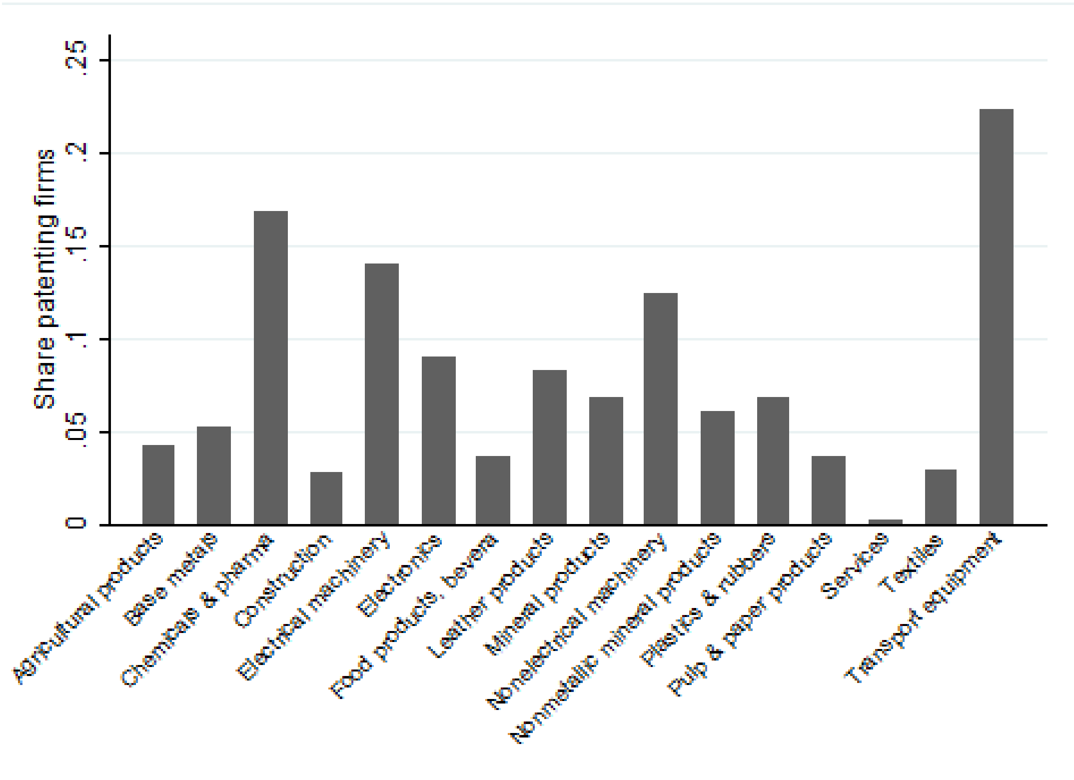

Figure 2: Clause 49A Requirements and Compliance Sheet for Companies

This figure shows the official document that all firms listed on the BSE were required to complete as per Clause 49A.

Annexure I B

Format of Quarterly Compliance Report on Corporate Governance

Name of the Company:
Quarter ending on:

Particulars	Clause of Listing agreement	Compliance Status Yes/No	Remarks
I. Board of Directors	49 I		
(A)Composition of Board	49(IA)		
(B)Non-executive Directors' compensation & disclosures	49 (IB)		
(C)Other provisions as to Board and Committees	49 (IC)		
(D)Code of Conduct	49 (ID)		
II. Audit Committee	49 (II)		
(A)Qualified & Independent Audit Committee	49 (IIA)		
(B)Meeting of Audit Committee	49 (IIB)		
(C)Powers of Audit Committee	49 (IIC)		
(D)Role of Audit Committee	49 II(D)		
(E)Review of Information by Audit Committee	49 (IIE)		
III. Subsidiary Companies	49 (III)		
IV. Disclosures	49 (IV)		
(A)Basis of related party transactions	49 (IV A)		
(B)Board Disclosures	49 (IV B)		
(C)Proceeds from public issues, rights issues, preferential issues etc.	49 (IV C)		
(D)Remuneration of Directors	49 (IV D)		
(E)Management	49 (IV E)		
(F)Shareholders	49 (IV F)		
V.CEO/CFO Certification	49 (V)		
VI. Report on Corporate Governance	49 (VI)		
VII. Compliance	49 (VII)		

Note:

1) The details under each head shall be provided to incorporate all the information required as per the provisions of the Clause 49 of the Listing Agreement.

2) In the column No.3, compliance or non-compliance may be indicated by Yes/No/N.A.. For example, if the Board has been composed in accordance with the Clause 49 I of the Listing Agreement, "Yes" may be indicated. Similarly, in case the company has no related party transactions, the words "N.A." may be indicated against 49 (IV A).