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BOARD INDEPENDENCE AND INNOVATION

Mariana Campos Carvalho Coelho, 716

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Professor Miguel Ferreira

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Abstract

Legislation introduced in the U.S. in 2002/2003 significantly changed board composition of public firms by imposing a 50% independent directors' ratio. Research on the effect of independent directors is not consensual, implying that this exogenous shock is a unique opportunity to study their importance. This study answers the question of whether or not independent directors can effectively mitigate agency conflicts between shareholders and the management, having a positive impact on the choice of successful R&D projects. We find that an increase of board independence has a positive impact on patent counts. Hence, the results support that independent directors truly spur innovation and risk taking.

Keywords: innovation, corporate governance, board independence, patents

1. Introduction

Innovation has been for long regarded as one of the main drivers of economic development[1]. Its effect on gaining a competitive advantage, firm performance and productivity has been sustained (e.g. Ettlie 1998; Yeh et al. 2010; Vivero 2002) and, as such, there have been numerous attempts to explain its drivers, in order to define how to in fact boost it.

This study pursues the objective of discussing a possible innovation driver, using the 2002/2003 legislative exogenous shock in the US to conduct an empirical study on the effect of board independence on innovation in publicly traded US firms. I look into these firms prior and post the approval of the Sarbanes-Oxley Act in 2002 and NYSE and NASDAQ's subsequent rules on public companies issued in 2003. These produced an exogenous shock on board composition as they introduced new rules on board independence in public firms in the US so as to attempt to create sounder control mechanisms to avoid corporate and accounting frauds, as those witnessed at the time (namely Enron).

Existing literature suggests that the role of the Board of Directors (from here onwards, BoD), might be relevant for innovation, a risky but potentially high-return activity in the long-run. The BoD is composed by the Executive Directors and the Non-Executive Directors and is in charge of all major decisions, such as strategy, governance system and management policies in general, as well as ensuring that all legal requirements are met and that shareholder and firm value are maximized in the long-run (Clayman, Fridson and Troughton 2012). The Executives focus on the actual daily management of the firm, while the Non-Executives are entrusted with advising and monitoring the

[1] Namely after Schumpeter (1942).

management team, with their power deriving from being elected by the shareholders. The BoD, in particular the Non-Executives, is also in charge, for example, of proposing the nomination and removal of the CEO, who then chooses the remaining management team staff. Among the Non-Executives, there are Independent Directors (from here onwards, ID). It is important to refer that a Non-Executive Director is not necessarily an ID; a Non-Executive, by definition, has the role of advising and monitoring (namely, by evaluating the CEO and management team, voting in major financial decisions, etc), and not conducting daily managerial work at the company. An ID must have no material connection to the firm or its management[2]. Therefore, an ID must be a Non-Executive. The reverse, however, is not true. In the context of this study, we focus on the role of the Non-Executives who are also IDs.

Investing in innovation is a strategic decision and, as it escapes the scope of daily operation, it is a BoD issue and subject to voting in Board meetings. Considering that this particular decision is associated to an investment in the present which yields an unpredictable return in the medium to long-term, Executives are likely to be more reluctant to accept to take such high risks (Baysinger, Kosnik, and Turk 1991) than Non-Executives, even assuming that innovation in general has a positive expected impact on the company's value. Therefore, it would be on the best interest of the shareholders to invest in innovation. Considering the risk-aversion behavior that the Executives are likely to have when analyzing a project with the aforementioned features, it might fall onto the Non-Executives to align the Research and Development

[2] NASDAQ and NYSE definition of ID: 1) Not an employee (or immediate family); 2) In general, direct compensation not higher than $100.000 (or immediate family); 3) Not an internal or external auditor (or immediate family) on the previous 3 years; 4) Not an executive (or immediate family) in a firm where a current executive has served in the compensation committee on the previous 3 years; 5) Not an executive or employee (or immediate family) of a company with significant business connections to the firm it currently serves on the previous 3 years. (NASD and NYSE Rulemaking)

(from here onwards, R&D) investment decision with the shareholders' interests in order to maximize firm value in the long-run. The CEO and the remaining management team are likely to focus on the present and on faster returns, as their job and compensation are linked to it, regardless of how foregoing a good investment opportunity might affect shareholder value in the long-run. However, if the IDs are a majority on the BoD, they will hold the majority of voting power and hence approve an innovation project if it is the case that they believe it will benefit the firm and its shareholders on the future, mitigating any agency problems that arise.

Therefore, considering the advantages of innovation in the medium to long-run, I test the hypothesis that a BoD with a majority of IDs will generate more innovation. In short, this study aims at testing if an increase on the weight of IDs on a BoD leads to increased levels of innovation and it concludes that in fact an increase in the proportion of independent directors has a significant positive impact on the variation of patents, a measure of (successful) innovation.

2. Literature Review

A common denominator to several studies in the innovation area is the role of the CEO. Several authors have analyzed distinct approaches to this topic. Generalist CEOs (i.e., with past work experience in distinct sectors), and an efficient labor market for executives for instance are proved to stimulate innovation (Custódio, Ferreira, and Matos 2014). For US data, long tenured CEOs are proved to harm R&D spending (Kor 2006). A higher sensitivity of the CEO's wealth to stock volatility is also shown to induce higher R&D spending (Coles, Daniel, and Naveen 2006), as well as option compensation schemes and higher CEO turnover are proved to drive innovation quantity and quality (Bereskin and Hsu 2011). Several other studies support that the

CEO’s past experience, invested wealth on the firm, age, self-confidence, among others, play an important role in innovation (Barker and Mueller 2002; Hirshleifer et al. 2012; Galasso and Simcoe 2010). Many other factors have been argued to stimulate innovation, namely the existence of large shareholders (Hill and Snell 1988). The positive impact of institutional ownership on innovation is also proved (Aghion, Reenen, and Zingales 2013), although it is contrary to the commonly accepted notion that these are short-term investors (i.e., Graves and Waddock 1990), hence harming innovation. All in all, these results support that sound decisions taken by the BoD, namely in terms of CEO characteristics and compensation schemes might spur innovation. The design of the latter might assist the Executives in overcoming short-term fears (Manso 2011) and, as such, providing the right incentives for them to pursue riskier and longer-term return projects, such as R&D. Issues such as CEO characteristics and compensation, although not dismissible in an overall analysis as they are a core function of the BoD, are not the focus of this study.

Our particular approach to the impact of board independence opposes to Baysinger et al. (1991) and Hill and Snell (1988), who advocate that a higher proportion of inside directors (i.e., Executives) promotes R&D spending. Baysinger et al. (1991) argue that this puzzling result might be due to the fact that Executives are more willing to invest in risky projects if they feel that they are significantly represented in the BoD, rather than if they are subject to scrutiny by a large proportion of outsiders (see also Adams et al. 2007). The authors recognize that these results are nonetheless contrary to the common understanding that Executives will be more risk averse, namely because they cannot diversify employment risk, and therefore choose to invest less in risky projects such as innovation at their current job (Baysinger, Kosnik, and Turk 1991). The view that

Independent Directors might not positively impact R&D is also supported by Kor (2006), who claims that the relationship is not significant probably due to the lack of involvement of outsiders on decisions. However, independence of the BoD promoted by the separation of the CEO role from the Chairman's is shown to be positive in terms of R&D intensity and has a high correlation to the ratio of outsiders. Therefore, the author also points out that his conclusion on the irrelevance of independence might be arguable, given that there is a strong substitution effect between managerial incentives and other governance mechanisms (Beatty and Zajac 1994; Kor 2006; Linck, Netter, and Yang 2008; Rediker and Seth 1995). However, for Kor (2006), given a long tenured CEO, shown to invest less in R&D, an outsider dominated BoD might not be effective in promoting R&D spending. Hence, board independence might not be the dominant effect in such a complex scenario.

Other compelling argument is that the increase of board independence has an heterogeneous effect on firms' performance (Wintoki 2007). One might conjecture whether or not this result might be applicable also to innovation. Following Wintoki's (2007) argument for firm performance, "young, small, growth firms operating in uncertain business environments, which are costly for outsiders to monitor" might also be harmed by these legislative changes in terms of innovation. Similarly, Duchin et al. (2010) identify distinct information processing costs associated to more outsider scrutiny for each particular firm. For firms in which there is a high information processing cost, outsiders might be a burden. Additionally, on this line of thought, and considering that the 2002/2003 independence requirements lead to some firms increasing their board size (by adding independent directors up to the 50% proportion) and some others to decrease it (by removing insiders to increase the weight of independent directors) (Armstrong, Core, and Guay 2013), the effect on innovation is likely to be heterogeneous. If in some contexts, larger BoDs might be necessary, namely due to the business' complexity, in some others it might add unnecessary complexity to decision making, especially if, as stated, information processing costs are high for outsiders. Hence, the effect of the legislative shock under analysis may differ according to the chosen path to achieve the 50% independence ratio.

The choice of BoD size and composition is also claimed to be highly endogenous to firm, industry and CEO characteristics (e.g. Linck et al. 2008; Coles et al. 2008; Wintoki 2007; Boone et al. 2007; Raheja 2005[3], Lehn et al. 2008), with R&D intensive firms being associated to higher proportions of insiders, given their clear advantage in firm-specific knowledge (Coles, Daniel, and Naveen 2008; Linck, Netter, and Yang 2008). Similarly, although monitoring quality has been shown to increase with independent directors oversight, intense BoD monitoring is claimed to come at the expense of its advising role, with poorer innovation and acquisition performance, especially for firms with high advising needs – complex ones – and in which innovation is a significant value creator (Faleye, Hoitash, and Hoitash 2011).

All of these challenge the idea that strongly independent boards are better in every perspective, namely in terms of innovation, and might lead to questioning the advantages of the imposition of a single BoD model by the 2002/2003 legislation. Our study is therefore relevant, as it isolates the BoD's independence effect with an exogenous shock on the proportion of outsiders. The fact that, after board and audit committee independence legislation in 2002/2003, firm transparency increased

[3] "The optimal board structure is determined by the trade-off between maximizing the incentive for insiders to reveal their private information, minimizing coordination costs among outsiders and maximizing the ability of outsiders to reject inferior projects." (Raheja 2005)

(Armstrong, Core, and Guay 2013) and accrual earnings management and opportunistic R&D expenses management decreased (Cohen et al. 2008; Peasnell et al. 2005; Klein 2002; Osma 2008) are optimistic hints that our hypothesis might be correct.

3. Research Design

3.1. Main variables and data

The sample period starts in 2000, considering it is the last year in which it was impossible to anticipate such regulatory changes (Armstrong, Core, and Guay 2013)[4]. Up until the first shareholder meeting after January 15, 2004 and no later than October 31, 2004, the BoDs of the firms affected by such regulatory changes had to adopt the required 50% independent directors' rule. Therefore, the choice of 2000 as the first year in the sample guarantees the use of an exogenous shock and data from 2004, the last year of the considered sample, already contemplates most of the changes in terms of BoD structure. This rationale is similar to that of Armstrong, Core and Guay (2013), who proved that an increase in the proportion of independent directors, as a result of this very same exogenous shock, improved firm transparency.

I use the databases (EXECUCOMP, BoardEx and the NBER patent database for innovation measures (Hall, Jaffe, and Trajtenberg 2001, 2005)) that cover American public firms. Firms operating in industries in which no patents were filled in the considered period are disregarded[5], as well as financial firms and utilities. Patent filling and their granting have, on average, a two-year lag and, considering that patents are only included in the database if they were eventually granted, patents filled in 2005 and

[4] Enron and Worldcom scandals, considered the main push for these regulatory changes, arose in 2001 and 2002 (Armstrong, Core, and Guay 2013).
[5] In order to test if results were robust when considering that may firms have zero patents filled in several years, Custódio, Ferreira and Matos (2014) test "if the results are driven by the jump from zero patents to at least one patent", by running the regressions without the zero-patent years, reaching similar results.

2006 might not yet be fully included in the 2007 database. Hence, it is advisable to end the reference sample in 2004, as it is done.

As control variables, the 2000 value for several firm-related measures were included (Armstrong, Core, and Guay 2013), namely Leverage, Firm Age, Monthly Return Volatility, Book-to-Market ratio and Business Diversification (see Table I – Variable Description). Contrary to Armstrong, Core, and Guay (2013), all change variables[6] are excluded. Not only did change variables tend to have strong correlations with the corresponding level variables, hence possibly generating a multicollinearity problem and distorting the results, but also, while Armstrong, Core, and Guay (2013) analyze the impact of independent directors on information, this study relates independent directors with innovation. Hence, in Armstrong, Core, and Guay (2013) a short term impact of independent directors is the focus. In this study, the focus is the effect on innovation, which tends to be a longer term outcome of a set of pre-conditions than information transparency. Therefore, the most relevant control variables to include would be those that would influence the decision to begin the research or its earlier stages, meaning the starting level of the firm's particular situation. These controls attempt to account for the most relevant exogeneous variables related to the firms' individual characteristics, which if ommitted could lead to biased results. These ommitted variables, if connected to the dependent variable, might be wrongly interpreted as an impact of the independent variable. Ommitted variables might also have an impact on both the dependent and independent variables, which might generate a spurious relationship[7]. For instance, Business Diversification is likely to influence both board structure and innovation. A

[6] Difference between the variable in 2004 and its initial value in 2000.

[7] Share Price, a proxy for perceived firm performance, R&D expense and Property, Plant and Equipment, a proxy for firm size, were omitted due to the low number of observations available for these indicators.

firm with more than one business segment might innovate more (as it has broader scopes to do so) and it is likely to be more complex, requiring a BoD with a more diversified skill set (and hence, probably, with more IDs). Other firm-related measures reflect the overall financial health of the firm and its size. A firm with lower leverage is probably more likely to be willing to invest in innovation, a risky project, as it can accommodate losses more easily than a highly levered firm.

3.2. Model Design

The first step into constructing the model was to define the relationship to be tested. In general terms, it can be defined as:

Change in Innovation Measure = f (Change in Board Structure, Control Variables)

However, a problem in estimating this relationship arises. Firms with a mindset of constantly being one step further in terms of innovation might require more and better advising in order to be able to cope with their own demands. Considering that a BoD with a diversified background and skill set is likely to provide a fresher view than an insider and that such a BoD is commonly considered a better one in terms of both its functions (advising and monitoring), there might be a trend towards having more innovative and fast moving firms hiring a higher proportion of independent directors. Therefore, innovation and the ratio of ID might be endogenously related, generating biased results if regressed with no further concerns. In order to use an OLS estimator, Gauss-Markov assumptions should hold, meaning namely that the error term of the regression should be uncorrelated to all independent variables, implying that all the factors left outside the regression (unexplained) contributing to innovation must not be in any way related to any of the independent variables. Considering that there might be some degree of influence of the innovation pace of the firm with its choice of BoD structure, ID is very likely to be endogenously related to innovation. In this scenario, the last assumption does not hold, leading to any conclusion derived from an OLS to be biased and inconsistent and, hence, have no validity[8].

Therefore, in order to estimate the model under analysis avoiding both the aforementioned simultaneity/reverse causality and also omitted variables biases, an instrumental variable had to be identified (Roberts and Whited 2013). Such a variable should fulfill two main conditions: relevance and exclusion. The former refers to the adequacy of using the instrument to predict the independent (endogenous) variable and is statistically translated by a nonzero correlation between the instrument and the independent endogenous variable[9]. The exclusion condition should guarantee that the instrument is related to the dependent variable only through the effect of the independent endogenous variable. Statistically, this means that the error term of the main regression must have a 0 covariance to the instrument[10]. In this case, a truly exogenous shock to the Independence Ratio, for sure with no correlation to the evolution of innovation, is provided by the regulatory changes of 2003. A variable based on this exogenous shock would have a direct impact on the ID ratio but not on the % Change of Patents. The only impact which is foreseeable to occur on the dependent variable is through the % Change of Independent Directors. The regulatory shock should then be used as an instrument to predict the final relationship between the analyzed variables.

[8] If ID was not correlated with any of the other explanatory variables, only the estimated impact of ID would be biased. However, correlations between ID and control variables are all different from 0. Therefore, all estimates would be biased (Roberts and Whited 2013).

[9] "…after netting out the effects of all other exogenous variables" (Roberts and Whited 2013)

[10] This is not possible to empirically test, as the error term is not truly observable.

A problem that arises in practice with the use of Instrumental Variables (IVs) is that it is empirically impossible to test their validity beyond any question. Some tests might be conducted although they are only “designed to rule out alternative hypothesis.”(Roberts and Whited 2013). Therefore, IVs must ultimately be considered valid based on the economic reasoning behind their choice. In this particular case, the choice of this regulatory shock is clearly reasonable, as there is no doubt it impacts the explanatory endogenous variable (% Change ID) and there is no reason whatsoever for it to affect innovation, other than through the % Change ID. Approving a law would have no effect on the actual firms unless the independence ratio is enforced. Moreover, institutional shocks are regarded as good basis for an instrument (Roberts and Whited 2013).

Having identified the basis for an appropriate instrument, a two-stage least squares approach is followed. The rationale of the first stage regression (which is in practice done simultaneously) is to estimate the predicted value of the % Change of Independent Directors, by doing a regression of % Change of ID on the control variables and the instrument and hence ensuring that the resulting prediction is exogenous. The second-stage expression is a regression of the % Change of Patents on the predicted value of the % Change of Independent Directors and the control variables.

The instrument is calculated using the Armstrong, Core, and Guay (2013) approach. From the Independence Ratio, a Minimum Percentage Change of Independent Directors (in order to comply with the 50% independent directors’ rule) is computed:

$$Min\ \%\ Change\ ID = Max\ (\frac{0.5 - Indep\ Ratio}{Indep\ Ratio}; 0)$$

In 2000, Compliant firms already have a 50% independent board and, as such, were required to make no changes – this variable assumes the value 0. Non-Compliant firms will have to adjust the proportion of Independent Directors, at least, to the 50% level. Therefore, the Min. % Change of ID reflects by which percentage firms would have to increase their IDs between 2000 and 2004 in order to be considered compliant at the end of the period. It is reasonable however to assume that in addition to the expected effect of the regulatory impositions, the Independence Ratio is also affected by a number of firm-level controls. Hence, the first stage equation is:

Regression I – Percentage Change of Independent Directors (Table III)

% Change of ID = f (Min % Change ID, Control Variables Level in 2000)

The final model to be estimated should, as referred, be instrumented for with the exogenous shock:

Regression II – Percentage Change in Patents (Table III)

% Change Patents = f (% Change ID (f (Min % Change ID)), Control Variables Level in 2000)

By inserting the variables used, Regression II is: *% Change of Patents = % Change of ID* $^{Regression\ I}$ *+ Diversification Dummy + Leverage + Firm Age + Volatility + Book-to-Market + Constant.*

4. Results

4.1. Descriptive Statistics

From 2000 to 2004, the 124 Non-Compliant firms (i.e., those below the 50% of independent directors in 2000) on average increased roughly 82% the proportion of independent directors on their board (Table II - Descriptive Statistics). The 716 firms for which there is data on IDs, on average, increased their weight of independent directors 24%. By 2004, close to 7% of the analyzed firms were not yet compliant with the 50% requirement. 5.56% of them were on the 50% threshold, with the remaining well above the requirement[11]. On average, the number of directors (board size) decreased slightly for both Compliant and Non-Compliant, with ID increasing and DD decreasing also for both. Firms in Compliance had almost twice the Independence Ratio (proportion of Independent Directors) in 2000 than Non-Compliant – roughly 69% against 35%, in line with Armstrong, Core, and Guay (2013). Compliant firms kept their proportion of ID stable (69% in 2000 and 70% in 2004), while Non-Compliant increased it significantly, from the referred 35% in 2000 to close to 71% in 2004.

As for innovation, the average number of patents filled decreased by close to 70% from 2000 to 2004, with 92% of the firms registering 0 patents in 2004, roughly 6% more than in 2000. On average, Compliant firms had 3.9 patents granted in 2000 and 1.2 in 2004, a decrease of close to 71%, while Non-Compliant firms registered an average of 46% decrease of patents granted, from 17.3 to 7.8.

4.2. Percentage Change of Independent Directors

Regression 1, referent to the percentage change of the ratio of independent directors (Table III – Regression I - Percentage Change of Independent Directors - First-stage), shows the significance of the minimum change required by law and the change observed in the IR. It is clear that the Min % Change of IDs that would have to occur, based on 2000 data, for firms to comply with the 50% independence requirement has a direct positive impact on the actual % Change of IDs for any degree of confidence. For

[11] Data obtained through the analysis of the data for the Independence Ratio in 2004.

each mandatory 1 percentage point of increase in terms of IDs, firms change board independence close to 5.67 percentage points. This is consistent with the fact that firms increased their IDs beyond the minimum requirement. It is also evidence of the fact that the instrument used is actually a proper one in terms of its strong effect on the explanatory variable. Jointly, the model explains roughly 30% of the variation in the % Change of IDs (R-Squared). If one removes the Min % Change of IDs, the explanatory power of the regression decreases considerably (Table III - Regression II - Percentage Change of Independent Directors - Auxiliary) to a close to 5% R-Squared. This is consistent with Armstrong, Core, and Guay (2013). Looking at the initial regression (Table III – Regression I), other control variables also have an effect on % Change of IDs. The latter is influenced, with a positive relationship, by the Diversification Dummy and Volatility and negatively by Firm Age and Book-to-Market. This might support that younger and more complex firms, with higher volatility of returns, tend to value outsiders' experience more than older firms with a single line of business. In these, it is probably more important to have a long experience in that particular area. The Book-to-Market value reflects the ratio of the firms' accounting value to its market value (market capitalization). The impact of this variable on ID, according to the model, implies that the higher the Book-to-Market (the more undervalued the firm becomes), the higher the negative impact on of IDs. This might be explained by a need to focus on the core of the firm and regain the markets' trust (a decreasing share price might be evidence of lack of confidence). Also, if a firm is undergoing financial difficulties it would lead to both a decrease in share price and also might also induce more insiders on the BoD, as they potentially know the firm better and reduce the scrutiny pressure on the management team, as referred on the Literature Review.

These results differ slightly from Armstrong et al. (2013), namely in terms of control variables. Nonetheless, the main variable, Min. % Change ID, also has a positive impact on the variation of IDs, although this study predicts a larger coefficient – hence, a stronger impact - of Min. % Change ID in the % Change ID.

4.3. Percentage Change of Patents

The previous results, showing that the variation of IDs in the aftermath of a legislative shock is not casuistic, enable the construction of the main model to be analyzed. The % Change of Patents is regressed on a set of variables. The base group, consisting of firms which did not need to increase the proportion of IDs, is composed of 330 firms, with the remaining 41 observations being firms which had to increase their IDs weight in order to become Compliant. From the output (Table III – Regression III - Percentage Change of Patents - Second-Stage) it is clear that the % Change of ID is highly significant and has a positive effect on the % Change of Patents. Considering the mean increase on the proportion of IDs, 24%, on average, firms increased their patent count by 6.48%. Other variables hold some explanatory power over the variation of patents, such as the levels of 2000's Leverage (negative relationship at a 10% confidence level) and Book-to-Market (positive relationship at a 1% confidence level). High leverage in a given period might induce cost cuttings in the following periods, if a firm attempts to rebalance its financials. Considering that R&D is a medium to long-term investment, cutting costs in 2000 would increase the probability of lower innovation levels in the following years. This is also evidence of the negative effect of leverage. As for Book-to-Market, it has a positive impact on patent variation, meaning that the more undervalued a firm becomes (or the higher its nets assets are in comparison to its share price), the more it innovates. This might be explained by a need to signal the markets that the firm is attempting to reinvent itself after a period in which its share price as decreased due to lack of confidence (which could have been the driver of the increase of Book-to-Market in the first place). A firm which becomes more overvalued (decreasing Book-to-Market) may not feel the need to invest as much in its own growth, as the markets, through an increase of share price, already recognize that it is becoming ever more valuable than its net assets.

5. Conclusions

This study provides evidence that innovation is influenced by board independence, with a strongly significant positive relationship between the variation in independent directors and patents. This result is in accordance with the commonly acknowledged concept that independent directors might assist in overcoming agency problems related to manager's risk taking. In this particular case, this problem concerns risk aversion. Innovation is generally seen as a long-term, costly project, with a highly uncertain return in a medium to long-term horizon. It is, therefore, in its essence, contrary to the manager's most common concern: immediate return with low costs, to ensure shareholders' profitability and safeguard its own job and bonuses. Independent directors, by having no material connection to the firm and its management and having as their mandate to monitor and advise the management so as to maximize firm and shareholder value in the long-run, inherently are more likely to support investment in innovation. This is supported by the model, which shows that by inducing a positive variation in the number of independent directors, a positive variation in patents is likely to occur.

However, merely increasing independent directors does not necessarily ensure that innovation is encouraged, although its influence is proved. As seen throughout the literature review, other factors have a crucial role in this regard, namely CEO-related factors. Hence, further research conducted with this regulatory shock should include an analysis on the CEO's characteristics and incentives. The current study might also be conducted with more recent patent data, considering that 2004 was, for some firms, the first year in which firms complied with the requirement. More recent patent counts might add strength to the argument, as the impact of IDs on innovation is expected to be long-term. Further study could also be made with a separation between firms which increased board size and those which decreased it (the majority) in order to test whether or not decreasing board size had an effect on innovation.

Furthermore, patents are only one of the possible measures of innovation. This study might also be replicated for an input innovation variable – R&D expenses – and for a quality measure of patents – citations. R&D expense does not necessarily generate innovation – in a worst possible case scenario, all expense might lead to no new findings – but it might be an approximation of the effort towards innovation. Citations are an actual quality measure for patents[12] and, as such, are a more complex innovation measure. Nonetheless, this study inevitably points towards a positive impact of this legislation in terms of innovation and hints that board independence is crucial to boost patents. The model, then, supports the view that IDs might ultimately mitigate agency conflicts arising between the management and the shareholders in terms of innovation and be a crucial to the stimulation of the decision to invest in R&D projects which actually result in patent granting.

[12] The number of citations reflects the number of times a given patent has been used in further developments (Custódio, Ferreira, and Matos, 2014).

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Annexes

Table I – Description of Variables

	Abbreviation	Description and Source
Number of Directors	-	Board size in absolute terms (IRRC).
Independence Ratio	IR	The ratio of independent directors to board size (IRRC).
Number of Independent Directors	ID	Number of directors with no material relationship to the company in absolute terms (computed from the Independent Ratio and Board Size).
Minimum Percentage Change of Independent Directors	Min %Change ID	Necessary change of Independence Ratio to reach the 50% requirement. Equals 0 if the Independence Ratio if larger than 50% in 2000 and the minimum percentage change required to achieve the 50%
Percentage Change Independent Directors	% Change ID	Percentage variation of the number of Independent directors between 2000 and 2004 (computed with the number of ID in 2000 and 2004). Winsorized at 1%.
Dependent Directors	DD	Number of directors who are executive or have a material relationship to the company (computed from the difference of Board Size (Number of Directors) and Independent Directors).
Leverage	Leverage	Ratio of long-term debt and current liabilities to total assets (Compustat). Winsorized at 1%.
Firm Age	Firm Age	Number of years in which the firm had its shares listed (CRSP). Logarithmized.
Monthly Return Volatility	Volatility	Standard deviation of monthly stock returns (CRSP). Winsorized at 1%.
Book-to-Market Ratio	Book-to-Market	Ratio of book to market value (Compustat). Winsorized at 1%.
Diverfication Dummy	Div. Dummy	Dummy variable that assumes the value 1 if a firm operates in more than one business segment and 0 otherwise (Compustat).
Patent Number	Patents	Number of patent applications by a given firm in an individual year (NBER database).
Percentage Change Patent Number	% Change Patents	Percentage variation of the number of patents between 2000 and 2004 (computed with the number of patents in 2000 and 2004). Winsorized at 1%.
Research and Development	R&D	Ratio of research and development expenses to total assets (Compustat).
Citations	-	Adjusted citation count for all patents a firm applied for in a given year - following Custódio et al. (2014) and Hall, Jaffe and Trajtenberg (2001, 2005) (NBER patent database).

Table II – Descriptive Statistics

	Date	Mean	St Dev	Min	Max
Number of Directors	2000	9,054	2,605	4	25
	2004	8,933	2,227	4	16
Independence Ratio	2000	0,630	0,180	0	0,938
	2004	0,704	0,146	0	1
Detail if Min % Change > 0[1]	2000	0,351	0,092	0,111	0,467
	2004	0,709	0,154	0,4	0,909
Detail if Min % Change = 0[2]	2000	0,692	0,129	0	0,938
	2004	0,704	0,146	0	1,0
Number of Independent Directors	2000	5,754	2,425	0	17
	2004	6,321	2,151	0	15
Winsorized Min % Change of ID	2000	0,001	0,013	0	0,1
Detail if Min % Change > 0[1]	2000	0,123	0,009	0,071	0,1
Winsorized % Change ID 2000-2004	2000-2004	0,240	0,515	-0,500	3
Detail if Min % Change > 0[1]	2000-2004	0,822	0,813	-0,333	3
Number of Dependent Directors	2000	3,300	1,826	1	10
	2004	3,227	2,474	0	10
Diversification Dummy	2000	0,611	0,488	0	1
Winsorized Leverage	2000	0,226	0,185	0	0,828
Log of Firm Age	2000	2,631	1,021	0	4,317
Firm Age	2000	14	3	1	75
Winsorized Volatility	2000	0,179	0,083	0,031	0,374
Winsorized Book-to-Market	2000	0,608	0,313	0,112	1,248
Patent Number	2000	4,061	57,188	0	4104
	2004	1,337	17,272	0	911
Detail if Min % Change > 0[1]	2000	17	108	0	1365
	2004	8	41	0	423
Detail if Min % Change = 0[2]	2000	4	56	0	4104
	2004	1	17	0	911
Winsorized % Change Patent 2000-2004	2000-2004	-0,697	0,513	-1	1,5
Detail if Min % Change > 0[1]	2000-2004	-0,487	0,649	-1	1,5
Detail if Min % Change = 0[2]	2000-2005	-0,706	0,504	-1	1,5

[1] Firms which had to increase their independence ratio.

[2] Firms which were already in compliance in 2000.

Table III - Regression Outputs

Regression I - Percentage Change of Independent Directors - First-stage linear regression

% Change ID	Coefficient	t	P>|t|		
Min % Change ID	5.672	9.27	0.000		
Div. Dummy	0.073	1.95	0.051	Nr. Obs.	659
Leverage	0.000	0.00	0.999	R-squared	0.3068
Firm Age	-0.045	-2.45	0.015		
Volatility	0.617	2.42	0.016		
Book-to-Market	-0.133	-2.29	0.022		
Constant	0.187	2.04	0.041		

Regression II - Percentage Change of Independent Directors - Auxiliary linear regression

% Change ID	Coefficient	t	P>|t|		
Div. Dummy	0.076	1.75	0.081		
Leverage	-0.086	-0.73	0.469	Nr. Obs.	659
Firm Age	-0.090	-4.18	0.000	R-squared	0.0449
Volatility	0.235	0.83	0.406		
Book-to-Market	-0.148	-2.21	0.028		
Constant	0.522	5.17	0.000		

Regression III - Percentage Change of Patents - Instrumental variables (2SLS) regression

% Change Patents	Coefficient	t	P>|t|		
% Change ID	0.267	2.20	0.028		
Div. Dummy	-0.042	-0.62	0.537	Nr. Obs.	371
Leverage	-0.339	-1.73	0.083	R-squared	0.0211
Firm Age	0.038	1.06	0.287		
Volatility	0.240	0.57	0.572		
Book-to-Market	0.319	2.82	0.005		
Constant	-0.881	-5.17	0.000		