Innovation by start-up firms: The role of the board of directors for knowledge spillovers[?]

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Abstract

This paper investigates whether board directors interlocked with or employed by innovative firms affect start-up firms' propensity to be innovators themselves. Drawing upon a sample of more than 50,000 Swedish start-up firms, we find that board connections to incumbent innovators have a causal impact on the new firms' probability to apply for patents. The results are robust when controlling for industry, geography, firm age, as well as spillovers through worker and managerial mobility, external knowledge sourcing through patent disclosure, access to venture capital and board attributes.

Keywords: start-ups, board of directors, knowledge spillovers, innovation, instrumental variables estimation

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1. Introduction

Research has shown that technological knowledge is a key resource for the competitive advantage of innovative firms (Agarwal, Echambadi, Franco and Sarkar, 2004; Kogut and Zander, 1992; Audretsch and Lehmann, 2006). In most technology fields, progress draws upon knowledge from a number of earlier discoveries and experiences (Dosi and Nelson, 2010). Therefore, new entrants to the market, due

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to their lack of experience, can encounter difficulties without external contact to established organizations or individuals (Dalziel, Gentry and Bowerman, 2011; Jones, Coviello and Tang, 2011). However, the capacity of start-ups to access and absorb external knowledge (Cohen and Levinthal, 1990) may be constrained by a limited endowment of initial knowledge and financial resources.

Building on the Schumpeterian view that incumbent organizations represent the origin of the innovation opportunities exploited by entrepreneurial start-up firms, scholars have investigated whether spin-offs may appropriate knowledge spillovers from their parents, fostering innovation and in turn productivity and growth (Acs et al., 2013; Eckhardt and Shane, 2003; Klepper and Sleeper, 2005; Klepper, 2010; Koellinger, 2008; Vaghely and Julien, 2010). Our paper takes a different perspective on knowledge spillovers and resource-constrained entrants by investigating the role of boards of directors for inter-firm links. We consider both inside and outside directors.[1]

So far, we know very little about the the ability of directors associated with innovative incumbents to support innovation in new firms. Prior works have almost completely neglected this role of board directors for innovative start-ups. Based on theoretical frameworks of knowledge spillovers, we address this gap by exploiting Swedish employer-employee panel data, formal intellectual property rights protections measures and appropriate identification strategies.

While the principal-agent relationship and corporate control are main objectives for the board of directors in large and listed corporations (Daily and Dalton, 1992; Kao, Hodgkinson and Jaafar, 2019; Shapiro, 2005; Solomon, Bendickson, Marvel, McDowell and Mahto, 2021), evidence from the literature shows that board members often serve as an extension to the management of small and young firms (Zahra and Filatotchev, 2004; Zhang, Baden-Fuller and Pool, 2011; Bizjak, Lemmon and Whitby, 2009; Brown, 2011; Shropshire, 2010). In this function, directors may assist the firm with higher information quality (Rutherford and Buchholtz, 2007), valuable

[1] Inside directors are employed by the start-up firm, while outside directors are not. Inside directors may serve on the board of external firms. Outside directors may be employed at other firms, serve on external boards (interlocked), or may not be linked to other firms.

strategic advice (Kor and Sundaramurthy, 2009

Colombelli, Grilli, Minola and Mrkajic, 2019; Klepper, 2001; Klepper and Sleeper, 2005), geographical and industrial clusters, relational networks, innovation systems and value chains (Breschi and Malerba, 2001; Feldman, 1994; Fritsch and Franke, 2004; Klepper, 2010; Rodríguez-Pose and Crescenzi, 2008). Our paper adds to this literature by examining the role of the board of directors for knowledge spillovers among innovative start-up firms. A vibrant stream of research on spillovers also focuses on technological opportunity and technological distance (Bloom, Schankerman and Van Reenen, 2013; Lychagin, Pinkse, Slade and Van Reenen, firms.

While spillovers can erode or destroy technological competencies for the firm ments and data on technological innovations from U.S. public companies and finds that more industrially diverse interlocks will have a greater impact on corporate technological innovation.

offs or spin-outs,[4] and new firms with only one employee throughout the sample period. Information on boards of directors is retrieved from the Swedish Companies Registration Office.

Table 1: Variable descriptions I: Categories of directors

Category 1:	
(i)$_{i;t\ 1}$	Inside director with no interlocking board
(ii)$_{i;t\ 1}$	Inside director interlocked with board of one or more non-innovative firms
(iii)$_{i;t\ 1}$	Outside director employed in a non-innovative firm and not interlocked with any board
(iv)$_{i;t\ 1}$	Outside director employed in a non-innovative firm and interlocked with board of one or more non-innovative firms
(v)$_{i;t\ 1}$	Outside director not employed in any firm and interlocked with board of one or more non-innovative firms
(vi)$_{i;t\ 1}$	Outside director not employed in any firm and not interlocked with board of any firm.
Category 2:	
(vii)$_{i;t\ 1}$	Inside director interlocked with the board of least one innovative firm
(viii)$_{i;t\ 1}$	Outside director employed in an innovative firm and with no interlock
(ix)$_{i;t\ 1}$	Outside director employed in a non-innovative firm and interlocked with the board of one or more innovative firms
(x)$_{i;t\ 1}$	Outside director employed in an innovative firm and interlocked with the board of one or more non-innovative firms
(xi)$_{i;t\ 1}$	Outside director employed in an innovative firm and interlocked with the board of one or more innovative firms
(xii)$_{i;t\ 1}$	Outside director not employed in any firm and interlocked with the board of one or more innovative firms

Table 2: Variable descriptions II

Dependent variables	
$\text{Patent}_{i,t}$	indicator (0/1): firm i applied for one or more patents in year t.
$\text{Trademark}_{i,t}$	indicator (0/1): firm i registered one or more trademarks in year t.
Key determinant	
$\text{BCI}_{i,t-1}$	equals 1 if any of the directors on the board are connected to an innovative (patent) firm (Category 2).
$\text{BCT}_{i,t-1}$	equals 1 if any of the directors on the board are connected to an innovative (trademark) firm.
Instruments	
$\text{New OBCI1}_{i,t-2}$	equals 1 if any of the outside directors were newly hired in a firm with patenting experience in year $(t-2)$ and were employed in a different firm without patenting experience in year $(t-3)$, 0 otherwise.
$\text{New OBCI2}_{i,t-2}$	equals 1 if any of the outside directors were newly hired in a firm with patenting experience in year $(t-3)$ and were employed in a different firm without patenting experience in year $(t-4)$, 0 otherwise.
$\text{New OBCT1}_{i,t-2}$	equals 1 if any of the outside directors were newly hired in a firm with trademark experience in year $(t-2)$ and were employed in a different firm without trademark experience in year $(t-3)$, 0 otherwise.
$\text{New OBCT2}_{i,t-2}$	equals 1 if any of the outside directors were newly hired in a firm with trademark experience in year $(t-3)$ and were employed in a different firm without trademark experience in year $(t-4)$, 0 otherwise.
Control variables	
$\text{Board size}_{i,t-1}$	number of directors on the focal firm's board.
$\log(\text{Total assets})_{i,t-1}$	log of total assets, winsorized.
$\text{Human capital}_{i,t-1}$	share of employees with three or more years of university education.
$\text{Metro}_{i,t-1}$	indicator (0/1): focal firm is located in metro area (Stockholm, Gothenburg or Malmö).
$\text{Firm age}_{i,t-1}$	firm age during the estimation sample, 2–10 years.
$\text{IE10}_{i,t-1}$	equals 1 if the share of employees whose last employment was with an innovative firm > 0.1, 0 otherwise
Additional controls	year and industry fixed effects

3.1. *Innovation measures*

In this subsection, we discuss the justification for our choice of dependent variables: patent applications and trademarks. It has been suggested that the protection of knowledge and technology as a competitive advantage is especially important for young companies. These often lack the control over their ownership and complementary assets for innovation which, in contrast, established and resourceful companies have (Teece, 1988).

A firm's knowledge or intellectual assets can be protected by patents, trademarks, copyright, secrecy, complexity, or first-mover advantage. Within this set of protection mechanisms, patents are the most studied mechanism in the literature (for a survey, see Hall, Helmers, Rogers and Sena, 2014). Patents offer a standardized and transparent measure of inventive activity (Popp, 2019). They contain information on the prior knowledge on which the patents are based, and identify individuals, firms and organizations. Patents provide a good indicator of R&D (Griliches, 1991), and they may also capture non-formal research investments. Moreover, patents are often a predictor of new product announcements (Artz, Norman, Hatfield and Cardinal, 2010), although with variation across firm sizes (Arundel, 2001) and industries (Mansfield, 1986). On the other hand, a well-known insight from this literature is that patents have drawbacks as indicators of innovation and are not always the most suitable measure of firms' intellectual assets. Therefore, we observe another instrument for protecting intellectual property, which recently has receives increased attention in research: the registration of trademarks.

Both patents and trademarks as formal appropriation mechanisms provide the owner with the exclusive right to use or sell the invention, and they are found to be both substitute and complementary modes of protection (Block, De Vries, Schumann and Sandner, 2014; Zhou, Sandner, Martinelli and Block, 2016; Veugelers and Schneider, 2018). A trademark is a word, symbol, or other expression used to distinguish a good or service produced by one firm from the goods or services of other firms (Landes and Posner, 1987). Trademark registration is relatively inexpensive and straightforward and may therefore suit resource-scarce innovative start-ups (for a recent survey, see Block, Fisch, Hahn and Sandner, 2015). Also, trademarks seem to have a similar effect as patents on firm value, productivity, and survival (Sandner, 2009; Crass, 2020).[5]

Especially for young companies, protection of intellectual property (IP) is not solely about reducing the risk of imitation, infringement and theft of their invention. IP rights may also have a signaling value to investors and can serve as collateral in financial markets. Being financially constrained, small firms may lack the resources needed to produce and commercialize the innovation (Hall and Lerner, 2010), and may lack access to financial markets. Patents and trademarks have also been found to facilitate licensing of the invention, improving the attraction of brands (Veugelers and Schneider, 2018), and enhancing reputation (Audretsch, Bönte and Mahagaonkar, 2012; Söderblom, Samuelsson, Wiklund and Sandberg, 2015; Colombelli, Grilli, Minola and Mrkajic, 2019).

The innovation literature contains a variety of other measures to compare companies' ability to generate new ideas besides patent applications and trademarks. However, most of them are not applicable to a study on start-ups. The firms in our sample are young and have a maximum of 9 employees in the year of their formation. First, while R&D is a common measure for studying investment in technological development, it is less relevant for young and small firms with mainly informal innovation activities. Second, the European Community Innovation Survey (CIS) has successfully introduced *innovation sales* as an innovation measure suitable for both manufacturing and service companies. However, among innovative start-ups, it is common that the market introduction of new products or services takes several years, which means they do not have any sales revenue from innovations. Third, using granted patents or citation-weighted patents instead of patent applications is not possible due to the long time lag. Fourth, total factor productivity is not a meaningful measure of innovation and technical change for new and small entrants on the market. Finally, we are not able to observe intellectual property protection mechanisms such as secrecy, complexity or first-mover advantage for the start-ups

[5] For more detailed discussions on the role of intellectual property rights as innovation indicators, see among others Verhoeven, Bakker and Veugelers (2016), Nagaoka, Motohashi and Goto (2010), Holgersson (2013), Morrar (2014), Gotsch and Hipp (2012) and Mendonça, Pereira and Godinho (2004).

in our sample.

4. Empirical models and identification strategy

Our empirical models analyze the influence of directors' external connections on firms' propensity to be innovative, using patent applications and granted trademarks one or more 'Category 2' directors, as defined in Table 1, on the board. To allow for the potential endogeneity of that measure, we construct two instruments using information on innovation characteristics of firms other than the focal firm. The first instrument variable $NewOBCI1_{i;t-2}$ equals 1 if any of the outside directors in year $t-2$ who were appointed to the focal firm's board in $t-3$ or earlier were newly hired in a firm with patenting experience in year $t-2$ and were employed in a different firm without patenting experience in year $t-3$, and equals 0 otherwise. Our second instrument, $NewOBCI2_{i;t-2}$, equals 1 if any of the outside directors in year $t-2$ who were appointed to the focal firm's board in $t-4$ or earlier were newly hired in a firm with patenting experience in year $t-3$ and were employed in a different firm without patenting experience in year $t-4$, and is 0 otherwise.

We assume that the owners of the focal firms cannot foresee that elected directors will change their place of work in the future, so that the instruments can be considered as predetermined. Furthermore, we conjecture that there is some stickiness in the composition of the board, so that current directors are more likely to be candidates and will be reelected in the following year. Changes in the external directors' employment can thus be argued to be exogenous to the focal firm.

For firm i in industry j and time t, the model is

$$Pr[Y_{i;t} = 1] = (BCI_{i;t-1} + X^{0}_{i;t-1} + {}_{j} + {}_{k} + {}_{t} + e_{i;t}) \tag{2}$$

where $Y_{i;t}$ is an indicator of whether the focal firm applied for any patents during year t, and $BCI_{i;t-1}$ indicates whether any of the inside or outside directors on the focal firm's board have connections to innovative firms. $X_{i;t-1}$ is a vector of firm-specific control variables including firm age, total assets, human capital, metro location, board size and share of employees with work experience in innovative firms. The symbols ${}_j$, $+ {}_k$ and ${}_t$ denote industry, cohort and year fixed effects, respectively.

Equation (2) estimates the new firms' propensity to be innovative, proxied by patent applications. To handle potential endogeneity we specify a second equation:

$$BCI_{i;t\ 1} = X^{0}_{i;t\ 1\ 0} + {}_{1}NewOBCI1_{i;t\ 2} + {}_{2}NewOBCI2_{i;t\ 2} + {}_{j} + {}_{k} + {}_{t\ 1} + {}_{i;t\ 1} \quad (3)$$

Equations (2) and (3) are estimated applying a recursive bivariate probit model. Following procedures suggested by Wooldridge (2005), Papke and Wooldridge (2008) and Semykina (2018), we also apply a correlated random effects (CRE) approach by adding firm-specific time averages of all time-varying covariates to Equations (2) and (3). We also include firm-specific averages of year dummies to both equations as recommended by Wooldridge (2019) in the context of unbalanced panels.

5. Results

to non-innovative firms. Only a small fraction of start-ups have inside or outside directors associated with innovative firms via employment or their boards.

In our initial analysis, using a binomial probit model, we examine how the likelihood of patent applications varies across new firms with the presence of directors of each of the 12 types described in Table 1. The estimates are conditional on firm characteristics, industry classification, labor mobility from innovative firms, geographical location, and time effects as specified by Equation (1).

Table 5 presents results for the 12 models corresponding to these director types. The left panel (Category 1) reports estimates for the presence of directors not linked to innovative firms. The right panel (Category 2) shows estimates for the directors who are employed in or are members of the board in innovative firms.

We obtain negative and partially significant estimates for directors belonging to Category 1 with the exception of sub-group (v): outside directors not employed in any firm and interlocked with the board of one or more non-innovative firms.

5.2. The importance of board members linked to innovative firms

The binomial probit estimates presented above indicate the existence of knowledge spillovers between innovative firms and start-up firms through board members. The presence of directors connected to innovative firms is positively associated with start-up firms' likelihood to apply for a patent. However, the results may be biased by reverse causality: start-ups formed by innovative entrepreneurs are probably more likely to successfully recruit directors with links to other innovative companies.

To investigate whether board members linked to innovative firms through employment or board membership positively affect a start-up firm's propensity to be innovative, we need to ensure that the influence of board members is not affected by potential endogeneity. We address this concern by estimating the recursive bivariate probit model described by equations (2) and (3) in Table 7 and of weak instruments. Also, we cannot reject the hypothesis testing the overidentifying restrictions. Taken together, the test results suggest that our instruments are valid.

Concerning the controls, there are some di erences between the two models. The variables board size, total assets, human capital, and employees recruited from innovative firms are positive and highly significant in the pooled model, but not significant in the CRE model. An explanation for this is that the CRE model controls for the mean of all continuous covariates. This implies that the impact on

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6. Sensitivity analysis

In this section, comprehensive sensitivity analyses of the estimates reported in the results section are performed. We investigate the effect of the board members' characteristics, the impact of patent citations, educational background, the importance of venture capital, different restrictions on firm size, and other definitions for start-up firms. We also study alternative models and extensions of the estimation sample in Appendix 2, evaluating whether the restrictions imposed to define that sample are driving the results.

Our first robustness test concerns the results for the two categories of directors reported in Table 5. Estimating separate equations for the different characteristics of board members, we find that directors not linked to any external innovative firm may negatively influence the focal firm's propensity to apply for a patent. This result is confirmed in Appendix Table 11, where all variations of the board members' characteristics are estimated in one equation rather than 12 different equations.

In the second sensitivity test we consider the board members' educational background and educational diversity as indirect drivers of innovation. For this analysis we introduce two new variables. The first, board human capital (BHC), measures the fraction of directors with three or more years of university education. The second is the *Blau index* (Blau, 1977) capturing the diversity of the board members' educational background (BEB). The results are presented in Appendix Table 12. We find positive and highly significant coefficients for human capital and diversity in the first stage regression, while the diversity estimates are not significant in the second stage. Human capital is positive and highly significant in the pooled model, and insignificant in the preferred CRE model. The results suggest that the level of education and educational diversity of the board of directors are indirect drivers of innovation by influencing whether any of the directors on the board is connected to an innovative firm.

The third sensitivity test applies instrumental variables techniques to focus on the results presented in Table 7. A concern with the reported patent estimates is that we retain the companies that have applied for patents in a given year in our sample. These companies may be more likely than other firms to apply for patents in subsequent years. As we are not modeling this potential autocorrelation at the firm level, we evaluate its importance by restricting the sample to only include firms which have not applied for a patent in prior years. A firm will be excluded from the sample after its first patent application. Appendix Table 13 reports recursive bivariate probit estimates from this reduced sample. The results show that the magnitude of the BoD indicators' coefficient estimates are somewhat lower in both the pooled and CRE model compared to Table 7. However, they are still positive and highly significant.

Extensive research within various strands of management, entrepreneurship and finance provides evidence on the importance of venture capital (VC) for innovative small businesses. To investigate whether our results may be driven by access to VC rather than knowledge spillovers from board members, we compare two model specifications in Appendix Table 14. The first column presents results including a binary variable indicating whether the focal firm received any VC in year t 1reses52 01(res3(imp)11 ship between incumbents with registered trademark protection and start-ups seeking patent protection. This table shows that the instruments are positive and highly significant in the first stage of the recursive pooled and CRE models. The spillover measure reported in the second stage is positive and significant at the 1% level in both the pooled and CRE estimates. This provides evidence that there are knowledge spillovers not only from established patenting firms to future innovators but also from trademark companies to start-ups seeking patent protection. We do not conduct any further sensitivity tests of this result, but note that it is a new finding in the management and entrepreneurship literature that deserves further research.

Our next sensitivity tests consider the instruments. Appendix Table 17 presents IV linear probability model estimates to evaluate the validity of the instruments we have constructed. Two sets of results are reported. The first two columns report first and second stage estimates for the pooled model, while columns 3 and 4 reveal the corresponding estimates for the CRE approach. The instruments and the board variable are positive and highly significant in both models. Beyond this crucial result, our main interest is to test the validity of the instruments. The Kleibergen–Paap tests of both underidentification and weak instruments[6] and the Hansen J test of overidentifying restrictions provide satisfactory results.

Finally, we test the sensitivity of our results by altering our definition of start-ups, starting with the entire population of independent firms as sample *A1*. Relative to our estimation sample, this represents an increase by almost 60% from about 312,000 firm-year observations to 490,515 firm-years. In sample *A2*, we exclude firms that have spun out of an incumbent firm. This sample is 28% larger than our estimation sample. Sample *A3* adds a restriction on the number of employees during firm formation, excluding all firms with 10 or more employees when formed, and is thereby 17% larger than the estimation sample. Sample *A4* imposes the further restriction of dropping firms with only one employee over the sample period, and is the sample used for the estimation results reported above. The characteristics of these four samples are described in Appendix 2, Table 18.

[6] See Baum, Schaffer and Stillman (2007) for details of these tests.

In order to assess the impact of these restrictions, we apply the recursive bivariate probit model on all four samples and compare the results in Appendix 2, Table 19. The reported marginal estimates show that the causal impact from board members affiliated with innovative firms on the likelihood of patent applications is positive and highly significant regardless of sample definition.

The main finding from our results reported in Sections 5 and 6 is that start-ups with directors linked to innovative incumbents have a larger propensity to apply for patents than do other start-ups. This is true regardless of whether the incumbents are defined as innovative based on patent applications or trademark protection. Although previous research (Block, De Vries, Schumann and Sandner, 2014; Veugelers and Schneider, 2018; Crass, 2020) suggests that trademark registrations may be an attractive method to protect intellectual property for resource-scarce innovative start-ups, we do not find any evidence that they are affected by knowledge spillovers. This is a plausible finding considering that patents are a more comprehensive and advanced intellectual property protection mechanism and knowledge is a more crucial factor for acquiring patents compared to trademarks.

A challenging research issue is to explore restrictions for the directors' ability to transfer knowledge from current innovators to future innovators. In this paper we have considered the importance of their level of education and diversity of education. Both have indirect impacts on the propensity to apply for patents through the first equation in the recursive bivariate probit model, whereas these estimates are not statistically significant in the second (innovation) equation. Other possible restrictions for efficient spillovers include exhaustion of technological opportunities, technological distance and the concept that the ruling technological paradigms may hamper the efficiency of knowledge diffusion (Olsson and Frey, 2002). One obvious limitation of the strength of spillovers is a lack of absorptive capacity, which we account for by considering previous innovation experience, human capital, firm age, and firm size. We also allow firms to receive knowledge through patent citations, venture capital engagement, or through recruitment of employees from innovative firms rather than directors' linked spillovers. As the potential for spillovers may be dependent on the technological or geographical landscape, we include both as controls in the regression analysis. Another possible limitation of the directors' ability to transfer knowledge is if the spillover jeopardizes rather than enhances return on R&D investments in the incumbent firm by its use in the start-up firm. This effect, as well as the quality of innovations linked to incumbent firms is not considered in our study, as they require a longer time-frame of observations than available in our data.

7. Conclusions

Building on the idea that incumbent organizations represent the origin of the innovation opportunities exploited by entrepreneurial firms, prior studies have examined knowledge spillovers through firm and university spin-offs, geographical and industrial clusters, relational networks, innovation system and value chains. This paper takes a different perspective by investigating whether board directors interlocked with or employed by innovative firms affect start-up firms' propensity to be innovators themselves. To the best of our knowledge, this is the first paper that systematically studies the importance of board of directors as knowledge conduits for innovative start-ups.

Our basic framework is the knowledge spillover theory of entrepreneurship (KSTE) that explains why start-ups are an efficient conduit in turning knowledge spillovers into innovation, and how entrepreneurship is concerned with the start-up and growth of new enterprises. While the KSTE view predominately considers the one-way spillover process from incumbent organizations to entrepreneurial firms, our paper also relies on theoretical concepts of a two-way, mutually beneficial spillover between firms. Board directors linked to both innovative start-up and innovative incumbents raise the possibility of a bidirectional flow of knowledge between firms. Identifying the importance of this spillover channel our paper shed new light on the interplay between incumbent organizations and 364(sha969 Td gdire)-347unders
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based on a recursive correlated random effects probit model are robust when controlling for industry and geography, as well as spillovers via worker and managerial mobility, external knowledge sourcing through patent disclosure, access to venture capital and board attributes. We believe that our findings relevant for other knowledge based economies with board members in start-up firms linked to a network of firms through interlocks or employment.

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References

Acs, Z. J., Audretsch, D. B. and Lehmann, E. E. (2013), ‘The knowledge spillover theory of entrepreneurship’, *Small business economics* 41(4), 757–774.

Adams, R. B., Hermalin, B. E. and Weisbach, M. S. (2010), ‘The role of boards of directors in corporate governance: A conceptual framework and survey’, *Journal of Economic Literature*

Audretsch, D. B., Bönte, W. and Mahagaonkar, P. (2012), 'Financial signaling by innovative nascent ventures: The relevance of patents and prototypes', *Research Policy* 41(8), 1407–1421.

Audretsch, D. B., Keilbach, M. C. and Lehmann, E. E. (2006), *Entrepreneurship and economic growth*, Oxford University Press.

Audretsch, D. B. and Lehmann, E. (2005), 'Does the knowledge spillover theory of entrepreneurship hold for regions?', *Research Policy* 34(8), 1191–1202.

Audretsch, D. B. and Lehmann, E. (2006), 'Entrepreneurial access and absorption of knowledge spillovers: Strategic board and managerial composition for competitive advantage', *Journal of Small Business Management* 44(2), 155–166.

Audretsch, D. B., Lehmann, E. E. and Warning, S. (2005), 'University spillovers and new firm location', *Research Policy* 34(7), 1113–1122.

Audretsch, D. B. and Stephan, P. (1999), 'How and why does knowledge spill over in biotechnology', *Innovation, Industry evolution, and Employment* pp. 216–229.

Audretsch, D. B. and Stephan, P. E. (1996), 'Company-scientist locational links: The case of biotechnology', *The American Economic Review* 86(3), 641–652.

Audretsch, D., Colombelli, A., Grilli, L., Minola, T. and Rasmussen, E. (2020), 'Innovative start-ups and policy initiatives', *Research Policy* 49(10), 104027.

Autio, E. (1997), 'New technology-based firms in innovation networks symplectic and generative impacts', *Research Policy* 26(3), 263–281.

Balsmeier, B., Buchwald, A. and Stiebale, J. (2014), 'Outside directors on the board and innovative firm performance', *Research Policy* 43(10), 1800–1815.

Balsmeier, B., Fleming, L. and Manso, G. (2017), 'Independent boards and innovation', *Journal of Financial Economics* 123(3), 536–557.

Baum, C. F., Scha□er, M. E. and Stillman, S. (2007), 'Enhanced routines for instrumental variables/generalized method of moments estimation and testing', *Stata Journal* 7(4), 465–506.

Baumol, W. J. and Strom, R. J. (2007), ‘Entrepreneurship and economic growth’, *Strategic entrepreneurship journal*

Cai, Y., Dhaliwal, D. S., Kim, Y. and Pan, C. (2014), 'Board interlocks and the diffusion of disclosure policy', *Review of Accounting Studies* 19(3), 1086–1119.

Cassiman, B. and Veugelers, R. (2002), 'R&d cooperation and spillovers: some empirical evidence from belgium', *American Economic Review* 92(4), 1169–1184.

Chandy, R. K. and Tellis, G. J. (2000), 'The incumbent's curse? incumbency, size, and radical product innovation', *Journal of marketing* 64(3), 1–17.

Cohen, W. M. and Levinthal, D. A. (1990), 'Absorptive capacity: A new perspective on learning and innovation', *Administrative Science Quarterly* 35(1), 128–152.

Colombelli, A., Grilli, L., Minola, T. and Mrkajic, B. (2019), 'To what extent do young innovative companies take advantage of policy support to enact innovation appropriation mechanisms?', *Research Policy* p. 103797.

Crass, D. (2020), 'Which firms use trademarks? firm-level evidence from germany on the role of distance, product quality and innovation', *Industry and Innovation* pp. 1–26.

Daily, C. M. and Dalton, D. R. (1992), 'The relationship between governance structure and corporate performance in entrepreneurial firms', *Journal of Business Venturing* 7(5), 375–386.

Dalziel, T., Gentry, R. J. and Bowerman, M. (2011), 'An integrated agency–resource dependence view of the influence of directors' human and relational capital on firms' r&d spending', *Journal of Management Studies* 48(6), 1217–1242.

Dosi, G. and Nelson, R. R. (2010), Technical change and industrial dynamics as evolutionary processes, *in* 'Handbook of the Economics of Innovation', Vol. 1, Elsevier, pp. 51–127.

Eckhardt, J. T. and Shane, S. A. (2003), 'Opportunities and entrepreneurship', *Journal of management* 29(3), 333–349.

Feldman, M. P. (1994), *The geography of innovation*, Vol. 2, Springer Science & Business Media.

Jones, M. V., Coviello, N. and Tang, Y. K. (2011), 'International entrepreneurship research (1989–2009): a domain ontology and thematic analysis', *Journal of Business Venturing* 26(6), 632–659.

Kao, M.-F., Hodgkinson, L. and Jaafar, A. (2019), 'Ownership structure, board of directors and firm performance: evidence from taiwan', *Corporate Governance: The international journal of business in society* .

Klepper, S. (2001), 'Employee startups in high-tech industries', *Industrial and Corporate Change* 10(3), 639–674.

Klepper, S. (2010), 'The origin and growth of industry clusters: The making of silicon valley and detroit', *Journal of Urban Economics* 67(1), 15–32.

Klepper, S. and Sleeper, S. (2005), 'Entry by spino□s', *Management science* 51(8), 1291–1306.

Koellinger, P. (2008), 'Why are some entrepreneurs more innovative than others?', *Small Business Economics* 31(1), 21.

Kogut, B. and Zander, U. (1992), 'Knowledge of the firm, combinative capabilities, and the replication of technology', *Organization Science* 3(3), 383–397.

Kor, Y. Y. and Sundaramurthy, C. (2009), 'Experience-based human capital and

Lybaert, N. (1998), ‘The information use in a sme: its importance and some elements of influence’, *Small business economics* 10(2), 171–191.

Lychagin, S., Pinkse, J., Slade, M. E. and Van Reenen, J. (2010), Spillovers in space: does geography matter?, Technical report, National Bureau of Economic Research.

Mansfield, E. (1986), ‘Patents and innovation: an empirical study’, *Management Science* 32(2), 173–181.

Marin, A. and Sasidharan, S. (2010), ‘Heterogeneous mnc subsidiaries and technological spillovers: Explaining positive and negative e￿ects in india’, *Research Policy* 39(9), 1227–1241.

Marshall, A. (1890), ‘" some aspects of competition." the address of the president of section f–economic science and statistics–of the british association, at the sixtiet meeting, held at leeds, in september, 1890’, *Journal of the Royal Statistical Society* 53(4), 612–643.

Mendonça, S., Pereira, T. S. and Godinho, M. M. (2004), ‘Trademarks as an indicator of innovation and industrial change’, *Research Policy* 33(9), 1385–1404.

Miller, T. and del Carmen Triana, M. (2009), ‘Demographic diversity in the boardroom: Mediators of the board diversity–firm performance relationship’, *Journal of Management studies* 46(5), 755–786.

Morrar, R. (2014), ‘Innovation in services: A literature review’, *Technology Innovation Management Review* 4(4).

Nagaoka, S., Motohashi, K. and Goto, A. (2010), Patent statistics as an innovation indicator, *in* ‘Handbook of the Economics of Innovation’, Vol. 2, Elsevier, pp. 1083–1127.

Olsson, O. and Frey, B. S. (2002), ‘Entrepreneurship as recombinant growth’, *Small Business Economics* 19(2), 69–80.

Papke, L. E. and Wooldridge, J. M. (2008), 'Panel data methods for fractional response variables with an application to test pass rates', *Journal of Econometrics* 145(1), 121 – 133.

Popp, D. (2019), Environmental policy and innovation: a decade of research, Technical Report 25631, National Bureau of Economic Research.

Rodríguez-Pose, A. and Crescenzi, R. (2008), 'Research and development, spillovers, innovation systems, and the genesis of regional growth in europe', *Regional Studies* 42(1), 51–67.

Romer, P. M. (1990), 'Endogenous technological change', *Journal of political Economy* 98(5, Part 2), S71–S102.

Ruigrok, W., Peck, S. and Tacheva, S. (2007), 'Nationality and gender diversity on swiss corporate boards', *Corporate governance: an international review* 15(4), 546–557.

Rutherford, M. A. and Buchholtz, A. K. (2007), 'Investigating the relationship between board characteristics and board information', *Corporate Governance: An International Review* 15(4), 576–584.

Sandner, P. (2009), The market value of r&d, patents, and trademarks, *in* 'The Valuation of Intangible Assets', Springer, pp. 35–72.

Saviotti, P. P. (2007), 'On the dynamics of generation and utilisation of knowledge: The local character of knowledge', *Structural Change and Economic Dynamics* 18(4), 387–408.

Saviotti, P. P. et al. (1996), 'Technological evolution, variety and the economy', *Books* .

Schubert, T. and Tavassoli, S. (2020), 'Product innovation and educational diversity in top and middle management teams', *Academy of Management Journal* 63(1), 272–294.

Semykina, A. (2018), ‘Self-employment among women: Do children matter more than we previously thought?’, *Journal of Applied Econometrics* 33(3), 416–434.

Shapiro, S. P. (2005), ‘Agency theory’, *Annu. Rev. Sociol.* 31, 263–284.

Shropshire, C. (2010), ‘The role of the interlocking director and board receptivity in the di�usion of practices’, *Academy of Management Review* 35(2), 246–264.

Slater, S. F., Mohr, J. J. and Sengupta, S. (2014), ‘Radical product innovation capability: Literature review, synthesis, and illustrative research propositions’, *Journal of Product Innovation Management* 31(3), 552–566.

Söderblom, A., Samuelsson, M., Wiklund, J. and Sandberg, R. (2015), ‘Inside the black box of outcome additionality: E�ects of early-stage government subsidies on resource accumulation and new venture performance’, *Research Policy* 44(8), 1501–1512.

Solomon, S. J., Bendickson, J. S., Marvel, M. R., McDowell, W. C. and Mahto, R. (2021), ‘Agency theory and entrepreneurship: A cross-country analysis’, *Journal of Business Research* 122, 466–476.

Srinivasan, R., Wuyts, S. and Mallapragada, G. (2018), ‘Corporate board interlocks and new product introductJ 11.706 -21.669 Td [(and)(‘ce‘-21.669 Td [(the)-415Dm941529,)]TJ/
dractices’, (3),

Weitzman, M. L. (1998), ‘Recombinant growth’, *The Quarterly Journal of Economics* 113(2), 331–360.

Wooldridge, J. M. (2005), ‘Simple solutions to the initial conditions problem in dynamic, nonlinear panel data models with unobserved heterogeneity’, *Journal of Applied Econometrics* 20(1), 39–54.

Wooldridge, J. M. (2019), ‘Correlated random effects models with unbalanced panels’, *Journal of Econometrics* 211(1), 137–150.

Yang, H., Phelps, C. and Steensma, H. K. (2010), ‘Learning from what others have learned from you: The effects of knowledge spillovers on originating firms’, *Academy of Management Journal* 53(2), 371–389.

Zahra, S. A. and Filatotchev, I. (2004), ‘Governance of the entrepreneurial threshold firm: A knowledge-based perspective’, *Journal of Management studies* 41(5), 885–897.

Zhang, J. J., Baden-Fuller, C. and Pool, J. K. (2011), ‘Resolving the tensions between monitoring, resourcing and strategizing: Structures and processes in high technology venture boards’, *Long Range Planning* 44(2), 95–117.

Zhou, H., Sandner, P. G., Martinelli, S. L. and Block, J. H. (2016), ‘Patents, trademarks, and their complementarity in venture capital funding’, *Technovation* 47, 14–22.

Tables

Table 3: Summary statistics. Four years after firm formation.

Variable	Mean	Std. Dev.	Min.	Max.
Patent application$_t$	0.002	0.042	0	1
Trademark registration$_t$	0.001	0.031	0	1
BCI$_{t\ 1}$	0.02	0.141	0	1
BCT$_{t\ 1}$	0.025	0.156	0	1
NewOBCI1$_{t\ 2}$	0.001	0.03	0	1
NewOBCI2$_{t\ 2}$	0.001	0.026	0	1
NewOBCT1$_{t\ 2}$	0.002	0.042	0	1
NewOBCT2$_{t\ 2}$	0.001	0.031	0	1
Board size$_{t\ 1}$	1.55	1.035	1	19
Log(total assets)$_{t\ 1}$	14.2	1.046	9.11	21.4
Human Capital$_{t\ 1}$	0.194	0.327	0	1
Metro	0.409	0.492	0	1
IE10$_{t\ 1}$	0.064	0.244	0	1
BHC$_{t\ 1}$	0.174	0.353	0	1
BEB diversity$_{t\ 1}$	0.12	0.225	0	1
N		54801		

Table 4: Summary statistics for full panel

Variable	Mean	Std. Dev.	Min.	Max.
Dependent variables				
Patent application$_t$	0.001	0.036	0	1
Trademark registration$_t$	0.001	0.031	0	1
Board variables				
BCI$_{t\ 1}$	0.016	0.124	0	1
BCT$_{t\ 1}$	0.021	0.144	0	1
Instruments				
NewOBCI1$_{t\ 2}$	0.001	0.027	0	1
NewOBCI2$_{t\ 2}$	0.001	0.026	0	1
NewOBCT1$_{t\ 2}$	0.001	0.035	0	1
NewOBCT2$_{t\ 2}$	0.001	0.031	0	1
Control variables				
Board size$_{t\ 1}$	1.514	0.996	1	20
Log(total assets)$_{t\ 1}$	14.40	1.102	6.91	21.4
Human Capital$_{t\ 1}$	0.185	0.318	0	1
Metro	0.398	0.489	0	1
IE10	0.068	0.252	0	1
BHC$_{t\ 1}$	0.164	0.347	0	1
BEB diversity$_{t\ 1}$	0.113	0.219	0	1
Year				
2006	0.101	0.302	0	1
2007	0.103	0.305	0	1
2008	0.104	0.306	0	1
2009	0.105	0.307	0	1
2010	0.106	0.308	0	1
2011	0.108	0.311	0	1
2012	0.105	0.307	0	1
2013	0.099	0.299	0	1
2014	0.094	0.292	0	1
2015	0.073	0.26	0	1
Firm age				
4	0.175	0.38	0	1
5	0.155	0.362	0	1
6	0.137	0.344	0	1
7	0.121	0.326	0	1
8	0.105	0.306	0	1
9	0.087	0.282	0	1
10	0.073	0.26	0	1
11	0.061	0.24	0	1
12	0.051	0.219	0	1
13	0.035	0.183	0	1
N		312458		

Table 5: Patent application$_t$ - Probit estimates

	Patent application$_t$											
	Category 1						Category 2					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)
(i)-(xii)	-0.093	-0.055	-0.187	-0.002	0.137	-0.210	0.291	-0.025	0.474	0.161	0.713	0.633
	(0.031)	(0.040)	(0.043)	(0.027)	(0.047)	(0.069)	(0.189)	(0.109)	(0.048)	(0.111)	(0.100)	(0.122)
Log(total assets)$_{t\ 1}$	0.213	0.228	0.213	0.224	0.220	0.222	0.222	0.224	0.205	0.223	0.218	0.220
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.025)	(0.024)	(0.024)	(0.024)
IE10$_{t\ 1}$	0.500	0.498	0.490	0.497	0.500	0.494	0.495	0.498	0.469	0.496	0.470	0.492
	(0.052)	(0.051)	(0.052)	(0.052)	(0.051)	(0.052)	(0.051)	(0.051)	(0.053)	(0.052)	(0.053)	(0.052)
Constant	-6.751	-6.924	-6.562	-6.847	-6.790	-6.773.958Td[()]TJ/F5910.9091Tf28.773-3.91Tf28.03						

Table 6: Patent application$_t$ - Probit AME[a]

	Patent application$_t$											
	Category 1						Category 2					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)
(i)-(xii)	-0.000	-0.000	-0.001	-0.000	0.000	-0.001	0.001	-0.000	0.002	0.001	0.002	0.002
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log(total assets)$_{t-1}$	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table 7: Patent application$_{t}$ - Recursive bivariate probit estimates

	Pooled	CRE[a]
BCI$_{t\;1}$	1.300	1.335
	(0.174)	(0.168)
Board size$_{t\;1}$	0.192	0.080
	(0.042)	(0.105)
Board size$^{2}_{t\;2}$	-0.019	-0.014
	(0.004)	(0.009)
Log(total assets)$_{t\;1}$	0.202	0.083
	(0.024)	(0.066)
Human Capital$_{t\;1}$	0.389	-0.140
	(0.078)	(0.172)
Metro	0.046	0.046
	(0.062)	(0.063)
IE10$_{t\;1}$	0.421	-0.014
	(0.054)	(0.070)
Constant	-6.914	-7.062
	(0.649)	(1.221)
		BCI$_{t\;1}$
NewOBCI $_{t\;2}$	2.475	2.460
	(0.115)	(0.116)
NewOBCI2 $_{t\;2}$	1.922	1.922
	(0.110)	(0.109)
Board size$_{t\;1}$	0.485	0.440
	(0.018)	(0.032)
Board size$^{2}_{t\;2}$	-0.021	-0.022
	(0.002)	(0.002)
Log(total assets)$_{t\;1}$	0.075	0.006
	(0.012)	(0.026)

Human Capital$_{t\;1}$ 0.507 0.421 TJ -124.678 -14.446 Td [((0.012))-7057((0.026))]TJ -103.905 -14. 0Q 1.083

Table 8: Patent application$_t$ - Recursive bivariate probit AME[a]

	Pooled	CRE[b]
BCI$_{t-1}$	0.0053	0.0055
	(0.0012)	(0.0012)
Board size$_{t-1}$	0.0003	-0.0000
	(0.0001)	(0.0002)
Log(total assets)$_{t-1}$	0.0008	0.0003
	(0.0001)	(0.0003)
Human Capital$_{t-1}$	0.0016	-0.0006
	(0.0003)	(0.0007)
Metro	0.0002	0.0002
	(0.0003)	(0.0003)
IE10$_{t-1}$	0.0017	-0.0001
	(0.0003)	(0.0003)
Observations	312458	312458

Notes: BCI$_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. All specifications include year-, cohort-, industry- and firm age fixed effects Standard errors in parentheses, $p < 0.10$, $p < 0.05$, $p < 0.01$. [a] Average marginal effects. [b] Time averages of all time varying control variables included in both equations.

Table 9: Trademark registration$_t$ - Recursive bivariate probit estimates

	Pooled	CRE[a]
	Trademark registration$_t$	
BCT$_{t-1}$	-0.062	-0.083
	(0.219)	(0.201)
Log(total assets)$_{t-1}$	0.262	0.320
	(0.017)	(0.074)
IE10$_{t-1}$	0.224	0.037
	(0.055)	(0.132)
Constant	-7.293	-6.761
	(0.436)	(0.504)
	BCT$_{t-1}$	
NewOBCT1$_{t-2}$	2.318	2.315
	(0.088)	(0.088)
NewOBCT2$_{t-2}$	1.887	1.886
	(0.089)	(0.090)
Log(total assets)$_{t-1}$	0.054	-0.008
	(0.011)	(0.024)
IE10$_{t-1}$	0.135	-0.170
	(0.033)	(0.044)
Constant	-3.552	-3.146
	(0.230)	(0.336)
	0.257	0.260
	(0.122)	(0.112)
Observations	312458	312458

Notes: BCT$_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (trademark) firm. New OBCT1$_{i;t-2}$ (New OBCT2$_{i;t-2}$) indicates whether any of the outside directors were newly hired in a firm with trademark experience in year $t-2$ ($t-3$) and were employed in a different firm without trademark experience in year $t-3$ ($t-4$). All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects Clustered standard errors in parentheses, $p < 0.10$, $p < 0.05$, $p < 0.01$. [a] Time averages of all time varying control variables included in both equations.

Table 10: Trademark registration$_t$ - Recursive bivariate probit AME[a]

	Pooled	CRE[b]
BCT_{t-1}	-0.0002	-0.0002
	(0.0006)	(0.0006)
Log(total assets)$_{t-1}$	0.0007	0.0009
	(0.0001)	(0.0002)
$IE10_{t-1}$	0.0006	0.0001
	(0.0002)	(0.0004)
	(0.0001)	(0.0003)
Observations	312458	312458

Notes: $BCT_{i,t-1}$ indicates whether any of the directors on the board are connected to an innovative (trademark) firm. All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects Clustered standard errors in parentheses, $p < 0.10$, $p < 0.05$, $p < 0.01$. [a] Average marginal effects [b] Time averages of all time varying control variables included in both equations.

Appendix 1

Table 11: Patent application$_t$ - Probit estimates (12 categories)

	Patent application$_t$
Category 1:	
(ii)$_{t\ 1}$	-0.022
	(0.046)
(iii)$_{t\ 1}$	-0.096
	(0.050)
(iv)$_{t\ 1}$	0.052
	(0.039)
(v)$_{t\ 1}$	0.182
	(0.055)
(vi)$_{t\ 1}$	-0.169
	(0.077)
Category 2:	
(vii)$_{t\ 1}$	0.350
	(0.194)
(viii)$_{t\ 1}$	0.016
	(0.058)
(ix)$_{t\ 1}$	0.427
	(0.058)
(x)$_{t\ 1}$	0.146
	(0.129)
(xi)$_{t\ 1}$	0.628
	(0.100)
(xii)$_{t\ 1}$	0.579
	(0.133)

Table 12: Patent application$_t$ - Recursive bivariate probit estimates - Board educational background

	Pooled	CRE[a]
	Patent application$_t$	
BCI$_{t\ 1}$	1.280	1.305
	(0.176)	(0.169)
Log(total assets)$_{t\ 1}$	0.196	0.083
	(0.024)	(0.067)
BHC$_{t\ 1}$	0.261	0.288
	(0.070)	(0.264)
BEB diversity$_{t\ 1}$	-0.053	-0.040
	(0.135)	(0.267)
IE10$_{t\ 1}$	0.4290	

Table 13: Patent application$_t$ - Recursive bivariate probit estimates - No previous patents

	Pooled	CRE[a]
	Patent application$_t$	
BCI$_{t-1}$	0.954	1.200
	(0.273)	(0.347)
Log(total assets)$_{t-1}$	0.100	0.536
	(0.022)	(0.111)
IE10$_{t-1}$	0.384	0.315
	(0.066)	(0.150)
Constant	-4.521	-4.178
	(0.448)	(0.508)
	BCI$_{t-1}$	
NewOBCI1$_{t-2}$	2.480	2.470
	(0.115)	(0.115)
NewOBCI2$_{t-2}$	1.930	1.935
	(0.112)	(0.111)
Log(total assets)$_{t-1}$	0.067	0.008
	(0.012)	(0.027)
IE10$_{t-1}$	0.270	-0.199
	(0.038)	(0.050)
Constant	-4.109	-4.417
	(0.293)	(0.531)
	-0.150	-0.238
	(0.124)	(0.155)
Observations	310886	310886

Notes: BCI$_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. New OBCI1$_{i;t-2}$ (New OBCI2$_{i;t-2}$) indicates whether any of the out-

Table 14: Patent application$_t$-Recursive bivariate probit estimates - Venture capital

		No VC in$_{t-1}$
	CRE[a]	CRE[a]
	Patent application$_t$	
BCI$_{t-1}$	1.272	1.257
	(0.171)	(0.175)
VC$_{t-1}$	0.496	
	(0.205)	
Log(total assets)$_{t-1}$	0.084	0.078
	(0.066)	(0.067)
IE10$_{t-1}$	-0.001	0.021
	(0.068)	(0.069)
Constant	-7.093	-7.134
	(1.246)	(1.248)
	BCI$_{t-1}$	
NewOBCI1$_{t-2}$	2.464	2.464
	(0.115)	(0.115)
NewOBCI2$_{t-2}$	1.927	1.928
	(0.109)	(0.109)
VC$_{t-1}$	1.637	
	(0.204)	
Log(total assets)$_{t-1}$	0.006	0.006
	(0.026)	(0.027)
IE10$_{t-1}$	-0.179	-0.185
	(0.047)	(0.047)
Constant	-4.581	-4.586
	(0.531)	(0.531)
	-0.256	-0.287
	(0.088)	(0.085)
Observations	312400	312400

Notes: BCI$_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. New OBCI1$_{i;t-2}$ (New OBCI2$_{i;t-2}$) indicates whether any of the outside directors were newly hired in a firm with patenting experience in year $t-2$ ($t-3$) and were employed in a different firm without patenting experience in year $t-3$ ($t-4$). All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects Clustered standard errors in parentheses, $p < 0.10$, $p < 0.05$, $p < 0.01$. [a] Time averages of all time varying control variables included in both equations.

Table 15: Patent application$_t$ - Recursive bivariate probit estimates - No citations

	CRE[a] Patent application$_t$ without citation to other patents$_t$
BCI_{t-1}	0.890
	(0.245)
Log(total assets)$_{t-1}$	0.083
	(0.079)
$IE10_{t-1}$	-0.175
	(0.114)
Constant	-7.259
	(1.262)
	BCI_{t-1}
$NewOBCI1_{t-2}$	2.469
	(0.115)
$NewOBCI2_{t-2}$	1.930
	(0.109)
Log(total assets)$_{t-1}$	0.007
	(0.026)
$IE10_{t-1}$	-0.182
	(0.047)
Constant	-4.615
	(0.532)
	-0.159
	(0.132)
Observations	312458

Notes: $BCI_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. New $OBCI1_{i;t-2}$ (New $OBCI2_{i;t-2}$) indicates whether any of the outside directors were newly hired in a firm with patenting experience in year $t-2$ ($t-3$) and were employed in a different firm without patenting experience in year $t-3$ ($t-4$). All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects Standard errors in parentheses, $p < 0{:}10$, $p < 0{:}05$, $p < 0{:}01$.[a] Time averages of all time varying control variables included in both equations.

Table 16: Patent application$_t$ - Recursive bivariate probit estimates - Trademark spillovers

	Pooled	CRE[a]
	Patent application$_t$	
BCT$_{t-1}$	1.174	1.208
	(0.169)	(0.168)
Log(total assets)$_{t-1}$	0.204	0.069
	(0.024)	(0.064)
IE10$_{t-1}$	0.465	-0.024
	(0.052)	(0.069)
Constant	-7.106	-7.291
	(0.640)	(1.195)
	BCT$_{t-1}$	
NewOBCT1$_{t-2}$	2.301	2.296
	(0.089)	(0.089)
NewOBCT2$_{t-2}$	1.878	1.875
	(0.090)	(0.090)
Log(total assets)$_{t-1}$	0.054	-0.009
	(0.010)	(0.024)
IE10$_{t-1}$	0.137	-0.175
	(0.033)	(0.044)
Constant	-3.541	-3.135
	(0.230)	(0.335)
	-0.363	-0.397
	(0.079)	(0.079)
Observations	312458	312458

Notes: BCI$_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. BCT$_{i;t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. New OBCT1$_{i;t-2}$ (New OBCT2$_{i;t-2}$) indicates whether any of the outside directors were newly hired in a firm with trademark experience in year $(t-2)$ ($(t-3)$) and were employed in a different firm without trademark experience in year $t-3$ ($t-4$). All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects. Standard errors in parentheses, $p < 0.10$, $p < 0.05$, $p < 0.01$. [a] Time averages of all time varying control variables included in both equations.

Table 17: Patent application$_t$ - IV Linear Probability Estimates

	Pooled		CRE[a]	
	BCI_{t-1}	Patent application$_t$	BCI_{t-1}	Patent application$_t$
BCI_{t-1}		0.034		0.034
		(0.013)		(0.013)
$NewOBCI1_{t-2}$	0.677		0.674	
	(0.026)		(0.026)	
$NewOBCI2_{t-2}$	0.532		0.529	
	(0.032)		(0.032)	
Log(total assets)$_{t-1}$	0.003	0.001	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.000)
$IE10_{t-1}$	0.020	0.005	-0.008	-0.001
	(0.002)	(0.001)	(0.002)	(0.001)
Constant	-0.059	-0.014	-0.070	-0.013
	(0.012)	(0.003)	(0.016)	(0.004)
Observations	312458	312458	312458	312458
Kleibergen-Paap rk LM statistic		173.203		174.748
χ^2 p-value		0.0000		0.0000
Kleibergen-Paap rk Wald F statistic		364.953		358.093
Hansen J statistic		0.882		0.890
χ^2 p-value		0.3477		0.3456

Notes: $BCI_{i,t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. New $OBCI1_{i,t-2}$ (New $OBCI2_{i,t-2}$) indicates whether any of the outside directors were newly hired in a firm with patenting experience in year $t-2$ ($t-3$) and were employed in a different firm without patenting experience in year $t-3$ ($t-4$). All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects Clustered standard errors in parentheses, $p < 0.10$, $p < 0.05$, $p < 0.01$.[a] Time averages of all time varying control variables included in both equations.

Appendix 2

Table 18: Samples

A: *All new firms formed in year t*	
A1	all independent firms
A2	independent firms, no spin-outs
A3	independent firms, no spin-outs, $<$ 10 employees at start
A4	independent firms, no spin-outs, $<$ 10 employees at start, and more than one employee throughout the sample period

Table 19: Patent application$_t$ - Recursive bivariate probit AME[a] - Sample A1-A4

		Pooled	CRE[b]
Sample A1	BCI_{t-1}	0.0048	0.0047
		(0.0009)	(0.0009)
	Log(total assets)$_{t-1}$	0.0008	0.0003
		(0.0001)	(0.0002)
	IE10_{t-1}	0.0018	-0.0000
		(0.0002)	(0.0003)
	Observations	490515	490515
Sample A2	BCI_{t-1}	0.0050	0.0051
		(0.0010)	(0.0010)
	Log(total assets)$_{t-1}$	0.0008	0.0003
		(0.0001)	(0.0003)
	IE10_{t-1}	0.0018	-0.0001
		(0.0003)	(0.0003)
	Observations	400757	400757
Sample A3	BCI_{t-1}	0.0049	0.0050
		(0.0011)	(0.0010)
	Log(total assets)$_{t-1}$	0.0008	0.0004
		(0.0001)	(0.0003)
	IE10_{t-1}	0.0016	-0.0001
		(0.0002)	(0.0003)
	Observations	365330	365330
Sample A4	BCI_{t-1}	0.0053	0.0055
		(0.0012)	(0.0012)
	Log(total assets)$_{t-1}$	0.0008	0.0003
		(0.0001)	(0.0003)
	IE10_{t-1}	0.0017	-0.0001
		(0.0003)	(0.0003)
	Observations	312458	312458

Notes: $\text{BCI}_{i,t-1}$ indicates whether any of the directors on the board are connected to an innovative (patent) firm. All specifications include controls for board size$_{t-1}$, board size$^2_{t-2}$, human capital$_{t-1}$ and metro as well as year-, cohort-, industry- and firm age fixed effects Clustered standard errors in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.[a] Average marginal effects. [b] Time averages of all time varying control variables included in both equations.

Table 21: Patent application$_t$ - Probit AME[a] - Inter/Intra-industry spillover

	Pooled	CRE[b]
$BCISI_{t-1}$	0.0016	0.0014
	(0.0007)	(0.0007)
$BCISS_{t-1}$	0.0031	0.0029
	(0.0004)	(0.0004)
$BCIDS_{t-1}$	-0.0017	-0.0017
	(0.0004)	(0.0004)
Log(total assets)$_{t-1}$	0.0007	0.0003
	(0.0001)	(0.0002)
$IE10_{t-1}$	0.0016	-0.0000
	(0.0002)	(0.0002)
Observations	312458	312458

Notes: $BCISI_{i;t-1}$