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The interaction between inter-firm and interlocking directorate networks on firm's new product development outcomes

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ABSTRACT
This paper explores the interaction between a prominent board of directors and the network of inter-firm relationships on new product development. Specifically, we posit a positive interaction effect between a prominent board and the inter-firm network and structural holes positions on the number of new products developed by the firm. We test the theoretical framework on a sample of 1,758 agreements among 1,890 biopharmaceutical firms over the period 2006-2010. We find that by filtering, complementing and legitimizing information coming from the inter-firm network, a prominent interlocking directorate network can improve the inter-firm network's effects on new product development. We discuss important implications for how inter-personal networks (such as the board interlock directorate network) help to develop the effectiveness of inter-firm relationship networks in achieving new product development outcomes.

Keywords: Inter-firm network, Interlocking directorate network, Innovation, New product development, Biopharmaceutical industry.

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1. Introduction

Whilst we now understand more about how individual networks impact the firm's performance, a recent trend in network research has shifted to investigating network effects on business outcomes across multiple networks (Ozmel et al., 2013). More specifically, management literature has investigated – independently - the impact of inter-personal networks, such as the interlocking directorate networks, and the inter-firm relationship networks on firm performance. Interlocking directorate networks act as an inter-personal channel by which information and knowledge resources are exchanged (Pfeffer and Salancik, 1978) to the benefit of the firm. Literature in this field has mainly focused on examining how the interlocking directorate networks affect economic and financial performance (Dalton et al., 1999; Peng and Luo, 2000; Non and Franses, 2007; Pombo and Gutiérrez, 2011; Kaczmarek et al., 2012; Horton et al., 2012; Croci and Grassi, 2013; Larcker et al., 2013; Li et al., 2013), enhance superior innovation performance (Wincent et al., 2010), influence strategic alliance formation (Gulati and Westphal, 1999), contribute to the strategic decision making process (Carpenter and Westphal, 2001), and finally foster internal innovation or external innovation (Hoskisson et al., 2002). Similarly, a lot of research has highlighted the importance of inter-firm network structural positions on the firm's performance. Indeed, according to social capital literature, the inter-firm network is itself a source of valuable resources through which the firm can improve its performance (Ahuja, 2000; Koka and Prescott, 2002; Soh, 2003; Salman and Saives, 2005; Zaheer and Bell, 2005; Maurer and Ebers, 2006; Acquaah, 2007; Wu, 2008; Schilling and Phelp, 2007; Gilsing et al., 2008; Padula, 2008; Vanhaverbeke et al., 2009; Phelps, 2010; Malik, 2011; Vanhaverbeke et al., 2012).

However, it remains unresolved how the benefits delivered through inter-personal networks can be channeled to improve the delivery of business outcomes in inter-firm level networks. A possible exception in literature is Wang et al., 2014. The study by Wang et al.,

(2014) investigates two different networks, i.e. social networks of researchers and networks of knowledge elements and their relation to the firm's propensity to patent. This study examines the impact of two different inter-personal networks (social network and knowledge network) on innovative performance.

Our study investigates the interaction effect of an important inter-personal network (interlocking directorate) and inter-firm network (inter-firm ties such as alliances) on the firm's innovative performance. To the best of our knowledge, no studies so far have investigated the interaction effect of these two kinds of networks on firm‘s innovation performance.

In exploring this issue we build on the notion of structural network position as the source of advantageous benefits such as information sources and exchange of knowledge and resources (Koka and Prescott, 2002). But we also note that advantageous structural network positions, such as prominent and structural holes positions, have possible drawbacks such as information redundancy (in the case of prominence) and lack of specialization and focus (in the case of structural holes) (Ahuja, 2000; Vanhaverbeke et al., 2009; Malik, 2011). These drawbacks limit the full potential of any positive impact that the aforementioned network positions have on the firm's innovation performance. Our intuition is that firms with two prominent networks can use the benefits derived from one network to counterweigh the drawbacks in another network and so realize full business outcomes. In our study, we argue that a firm having a prominent inter-personal network position (i.e. the interlocking directorate network) achieved through extensive direct and indirect board ties, can use information assets at its disposal at the board level to reduce potential drawbacks encountered in the firm's inter-firm network by filtering, complementing and legitimizing information that is used by the firm to achieve innovation outcomes (Pfeffer and Salancik, 1978; Hillman and Dalziel, 2003).

Thus, our research contributes to the recent social capital (SC) literature trend that explores multiple network effects on business outcomes (e.g. Ozmel et al., 2013) by developing a theoretical argument of how an inter-personal network (the board interlock directorate network) inter-acts with an inter-firm network (such as alliances) to enhance innovation outcomes. In addition, we empirically validate this framework.

In this study we specifically focus on new product development (NPD) performance as a measure of innovation outcome, because of its importance in our research context – the biopharmaceutical industry. Past research in this industry has considered NPD as a good proxy of innovation outcomes because developing new products provides successful firms with monopoly rents for 10-15 years (Rothaermel, 2001; George et al., 2001; Rothaermel, 2002; Rothaermel and Deeds, 2004; Lim et al., 2006). Hence, in the biopharmaceutical industry, NPD is increasingly a focal point of competition and often requires the development and successful implementation of novel process technologies that ensures firms achieve their ultimately economic objectives such as cash, market share and competitive advantages (Lieberman and Montgomery, 1988). As a result NPD has been considered as a key variable in alliance studies and has been utilized to address the impact of alliances in the innovation performance of the firm (Rothaermel, 2001; Rothaermel and Deeds, 2004; Faems et al., 2005; Perks and Jeffery, 2006; Nieto and Santamaria, 2007). However, despite its importance in the biopharmaceutical industry and its relevance in alliance literature, past studies employing network theory to link network structural dimensions to innovation outcomes have mostly neglected NPD as a dependent variable by concentrating more on patents as the measure of innovation performance (Ahuja, 2000; Salman and Saives, 2004; Shilling and Phelps, 2007; Gilsing et al., 2008; Padula, 2008; Phelps, 2010; Vanhaverbeke et al., 2009; Karamanos, 2012; Vanhaverbeke et al., 2012). An important exception is the recent study of Mazzola et al. (2015), in which the authors hypothesize a positive effect of some structural embeddedness network positions of the firm in its inter-firm networks on firm's NPD performance in the biopharmaceutical industry. The paper's empirical analysis shows that a prominent position of the firm in its network positively affects NPD performance, while structural holes positions seem to not effect NPD performance. Similarly, Wincent et al. (2010) show how high levels of board interlocking directorates have positive effects on innovation performance related to new product development. These recent studies enforce the importance of the contribution of this research. Indeed, while literature has acknowledged the relevance of inter-personal and inter-firm networks on improving NPD performance, no studies have focused on the interaction effects of these two networks like we do in this paper.

We test our theoretical framework on a set of 300 public companies in the biopharmaceutical industry and we get a positive confirmation of our hypotheses. Indeed, our results show how a prominent position of the firm's board in the directorates network reinforces the positive impact on NPD performance that prominent and structural holes positions in the firm's inter-organizational network have on the same performance variable.

The paper is organized as follows: In the next section, we develop the theoretical framework and a set of hypotheses. Section 3 discusses the research methodology and the dataset, and section 4 presents the model specification. In section 5 results of the empirical investigations are shown, while discussion about the contribution of this research and conclusions are presented in section 6.

2. Theory and hypotheses

In recent decades, SC theorists have elucidated why network benefits arise from the firm's structural positions – both theoretically and empirically. A firm can benefit from its network by accessing critical information in the network through multiple ties with many partners, i.e. through prominent positions (Koka and Prescott, 2008). First, firms pursuing prominence in the network have advantages arising from accessing key and valuable information available in the network. Indeed, a prominent position facilitates the exchange of a high volume of information and knowledge assets that the firm can use to its competitive advantage (Granovetter, 1973; Koka and Prescott, 2002). However, network prominence benefits go beyond access to include those based on affiliation; indeed such a position enables the firm to influence its partners in ways that enable it to pursue and establish its own strategic agenda, thus enhancing its own performance (Koka and Prescott, 2008). As Podolny (2001) points out, being included in several inter-firm relations is also a signaling device that denotes prominence and influence (Zamudio et al., 2014) and signals quality and status (Ozmel et al., 2013).

A prominent position depends on the prominence of firms connected to it (Ruhnau, 2000; Koka and Prescott, 2002; Koka and Prescott, 2008; Zamudio, et al., 2014). Prominent firms in networks benefit from accessing potentially valuable external information from all companies other than its immediate partners (Soh, 2003), from developing greater capacity to monitor their external environment and from finding new information and knowledge (Ahuja, 2000). Most of the empirical studies that examine the impact of network prominent positions employ a range of firm‘s innovation output types as the dependent variable. These studies include the positive predictions of network prominence on patenting frequency (Ahuja, 2000), number of product awards (Soh, 2003), patenting propensity (Salman and Saives, 2005), innovative output (Schilling and Phelps, 2007), non-core technology patent citations (Vanhaverbeke et al., 2012), and new product development (Mazzola et al., 2015). Indeed, the firm's prominence in its own industry has been positively associated with higher exploitative and explorative learning processes (Atuahene-Gima and Murray, 2007) that are acknowledged as highly influential in product development (Katila and Ahuia, 2002). Prominent firms develop capabilities in dealing with inter-firm relationships (Anand and Khanna, 2000; Kale and Singh, 2007; Wang and Zajac, 2007) that can be useful to improve collaborative product development processes. In addition, prominent firms, thanks to their reputation and status, can firstly and easily reach the most influential suppliers and hence access the best knowledge and capabilities for making the NPD process more successful (Primo and Amundson, 2002; Petersen et al., 2003; Ragatz et al., 2003; Oke et al., 2008; Mazzola and Perrone, 2013); finally, thanks to their experience and knowledge about the network, they can better select the most aligned patents or technologies that can trigger or strengthen the NPD process (Geum et al., 2013).

Structural holes represent the second key structural network position that affects the firm's innovation performance (Burt, 1992; Ahuja, 2000; Burt, 2004; Zaheer and Bell, 2005; Padula, 2008). Structural holes are gaps in information flows created when two unrelated firms are linked to the same ego firm but not to each other. The firm that bridges unconnected firms will be able to potentially access novel and diverse information that might positively affect the firm's innovation performance (Burt, 1992; 2004; Koka and Prescott, 2002). Structural holes provide connections with so-called weak ties which may be partners operating in different industries, markets or technologies (Gilsing and Nooteboom, 2005) or just simply diverse and non-redundant information from partners that help companies to increase the innovation performance (Ahuja, 2000; Koka and Prescott, 2002; Rothaermael and Deeds, 2004; Gilsing et al., 2008).

Empirical research on structural holes and their impact on innovation outcomes has produced mixed results that seem to depend on the type of innovation performance investigated. For example, Ahuja (2000) finds a negative relationship between bridging structural holes and the ability of the firm to develop new patents, while Padula (2008) finds that a firm occupying a position that bridges network clusters is able to improve its patent propensity. With regards to research that employs NPD as dependent variable, previous literature recognizes that structural holes may facilitate the development of new products (Mazzola et al., 2015). Structural holes provides connections with unusual ties operating in different industries, markets or technologies and access to diverse and non-redundant information that help companies to develop new ideas and technologies for developing new products (Hargadon and Sutton, 1997; Zaheer and Bell, 2005). For example, Hargadon and Sutton (1997) describe a process of brainstorming in which IDEO's employees use technological solutions from one industry to solve client issues in their own industry where the solutions are rare or unknown. IDEO's employees, act as technology brokers in different industries to improve the firm's likelihood of developing new products. Following such reasoning, Mazzola et al. (2015) hypothesize a positive influence of structural holes positions, in a network of inter-firm relationships, on firm's NPD performance. Through an empirical analysis they found that bridging structural holes does not seem to influence firm's NPD performance. In summary, mixed empirical results from past studies on the link between structural holes positions and product innovation may therefore point to the presence of an interacting factor, a gap that our study seeks to explore.

2.1 The interaction of the board's prominence with the inter-firm network positions

The interlocking directorate network and the inter-firm network are two important networks that have individually a positive effect on the innovation performance of the firm. Regarding the interlocking directorate network, literature on the board function outlines how the firm's board members are themselves providers of resources to the firm – reputation or prominence being one such key resource (Hillman and Daziel, 2003). In the resource provision function, the board provides advice and counsel on important matters such as strategy formulation, access to information from outside the firm, preferential access to valuable resources that may be obtained through the board members' personal contacts, skills and expertise and legitimacy (Pfeffer and Salancik, 1978). Each board director has an individual interlock directorate network that is the sum of the actual and potential resources embedded within, available through, and derived from the network of (direct and indirect) relationships possessed by the director as a result of sitting on boards of other companies. The SC aspects of the board, in its resource provision function, are obtained by aggregating the individual director SC to the board level (Haynes and Hillman, 2010). Given that information obtained through the board network affects other networks through such mechanisms as strategy formulation or provision of expert opinion by board members, to get a more complete understanding of the determinants of the firm's innovation performance, we need to investigate what board networks bring to the firm and how they interact with the firm's other key networks such as its inter-firm network and the effect of this interaction on the firm's frequency to develop new products.

Several scholars have established the importance of a prominent board on the firm's economic-financial performance broadly (Non and Franses, 2007; Horton et al., 2012; Croci and Grassi, 2013; Larcker et al., 2013; Li et al., 2013) and on NPD, in particular (Wincent et al., 2010). Germane to this study, a prominent board positively influences both the firms' process and product innovation (Wincent et al., 2010). In appointing board members, firms therefore pay attention to the resource provision function of the board and aim to enhance the board and therefore the firm's SC by appointing experienced executives with a track record and reputation within their industry (Haynes and Hillman, 2010). To achieve prominence in the interlock directorate network, firms appoint members who sit on boards of other reputable companies thus providing the focal firm board with direct and indirect benefits of information and knowledge access. The web of relationships in the interlock directorate network facilitates the exchange of fine grained information about the industry trends and strategies that would be of benefit to firms considering entering into or managing strategic inter-firm relationships. A directors' prominence and therefore the extant of information and knowledge benefits arising from their network, depends on the boards they sit on directly, and also on third party links through other co-directors. Therefore, the boards on which prominent directors sit on, achieve prominent positions in the interlock directorate network and are perceived to be of high quality (Haynes and Hillman, 2010). Summarizing, a firm with a prominent board is a firm whose directors are on average highly connected with other firms and, therefore are well informed about technology and market trends, opportunities and threats. Furthermore, such directors have vast experience in board decision-making issues and have solid reputations, so that they are likely to act more independently from the firm's management since they are careful to make decisions that do not alter their own reputations. At the same time we know that having a prominent position in the inter-firm network involves managers dealing with more specific and operative information. Indeed, although inter-firm agreements are often decided at board level, the execution of such agreements allow product managers to exchange specific information concerning therapeutic areas, technologies, intermediate products (such as genes and proteins), patents and manufacturing processes. Although such information is broadly advantageous for NPD (Mazzola et al., 2015), there are some possible drawbacks (Vanhaverbeke et al., 2009; Malik, 2011) mainly related to high volumes of information to be processed and excessive information specialization (Koka and Prescott, 2002). Processing high volumes of information might have adverse consequences when it is necessary to make fast decisions such as in NPD process contexts (Eisenhardt, 1989). Such adverse consequences might arise from the necessity to scan high information volumes resulting from being prominent and the need to filter redundant information, certify information flows as trustworthy and of high quality and suitable for the NPD process (Koka and Prescott, 2002). Finally, there is a tendency for excessive information specialization in firms with highly prominent positions in the inter-firm relationship network, which can limit the scope for the exploration of new markets and new solutions that often are required to develop new products (Sammarra and Biggiero, 2008; Vanhaverbeke et al., 2009; Malik, 2011).

We argue that a prominent board counterweighs such drawbacks when they occur in inter-firm networks by improving the effectiveness of information obtained in structural inter-firm network positions. Indeed, while occupying a prominent position in the inter-firm network allows product managers to acquire specific knowledge and information that are closely related to product development (Dyer and Singh, 1998; Gulati, 1999; Gulati et al., 2000; Koka and Prescott, 2002), board prominence, being related to board directors, mainly concerns wide and deep industrial knowledge. Board directors are therefore able to help the management of the firm to filter redundant information and certify incoming knowledge as legitimate and potentially useful for NPD. Indeed, prominent directors are more knowledgeable about technology and market trends in the industry which are needed to develop new products (Mizruchi, 1996). For example, in the biopharmaceutical sector, prominent directors are more likely to be well-informed about the latest technology trends, the most promising patents in the industry, or the new approaches in drug discovery other companies are investing in. Thus, a prominent board, functioning as a filtering mechanism, reduces the cost of finding useful information from the redundancy provided by the firm's prominence in the inter-firm ties network. Also, thanks to prominent directors, product development teams are able to focus on a set of shared knowledge and similar capabilities that enhance the speed of NPD (Rindfleisch and Moorman, 2001). Furthermore, prominent directors help in certifying information as legitimate for NPD. Indeed, we can expect prominent directors to take great care in evaluating board proposals because their own personal reputation is at risk (Podolny, 2001). Because prominent boards are made up of executives with a successful track record and status (Ozmel et al., 2013), they are careful not to be associated with bad decisions that can damage their own reputation. Such directors are in a good position to better evaluate objectively the reliability, the accuracy and the quality of information from inter-firm network sources. In doing so, prominent directors act as knowledge brokers that certify the available information that enhances NPD processes of the firm (Hargadon, 1998).

Furthermore, it is highly likely that prominent directors' experiences and connections span different industries from those tied directly or indirectly to the focal firm. Thus, prominent directors are a possible source of additional information that reduces the risk of excessive information specialization and allows the focal firm to better explore new markets and technologies and ultimately to improve its NPD processes (Katila and Ahuia, 2002). Finally, prominent directors are likely to use knowledge structures developed from their experience on other boards for speeding up decision-making processes and, particularly, new product development initiatives (Carpenter and Westphal, 2001). For instance, Useem (1982) observed that executives use their board appointments as a way to scan the environment for timely and pertinent information. Similarly, directors can learn about the efficacy of different practices and how to implement them properly by observing the consequences of management decisions (Haunschild, 1993).

Hence, from the foregoing we can posit that:

H1. *The interaction between a prominent board in the interlocking directorate network and a prominent position in its inter-firm relationship network is positively related to new product development.*

A firm that bridges structural holes is able to access potentially novel and diverse information from remote parts of its network that can enhance the firm's performance (Burt, 1992; McEvily and Zaheer, 1999). Nevertheless, information obtained from bridging structural holes is often distant and diverse from the core business of the firm. So, in such cases, searching for valuable information through structural holes may actually reduce rather enhance the propensity of the firm to develop new products. In addition to the challenge of dealing with many non-redundant and weak ties, firms may also have to handle diverse information effectively (Gnyawali and Madhavan, 2001). Most focal firms are limited in their ability to recognize, assimilate, transform, and exploit distant and diverse knowledge for effective product development (Cohen and Levinthal, 1990). Such limits result in excess information that lead to dis-economies of scale in their innovation effort (Shipilov, 2009). Moreover, when knowledge components become more diverse, the lack of specialization and focus make the recombination of this knowledge into new valuable ideas difficult – thus potentially decreasing the product development rate (Brusoni et al., 2001).

We argue that having prominent directors may help the focal firm deal with the possible drawbacks of inter-firm structural holes positions. Indeed, prominent boards – made up of prominent directors - act as channels of potentially valuable information to the focal firm that mitigate the impact of these drawbacks in two ways: firstly, counteracting the aforementioned drawbacks, and secondly adding complementary information. The counteracting effect happens in three ways. First, prominent directors can reduce the information asymmetry between distant ties in the inter-firm network. Prominent directors act as competent interpreters of information that is far from the core business of the firm and thus help the management to better understand and evaluate any “distant” information for the purpose of developing new products. Second, prominent directors help the focal firm to reduce the risk related with distant information because such directors are likely to be more aware of possible threats or failures experienced by other firms when dealing with “distant” information. Prominent directors can alert management of possible risks of failure involving certain NPD projects and in this way help the firm to avoid high risk paths. Finally, as well argued by Hoskisson et al. (2002), a director with a deeper knowledge of the market, also for the reasons previously mentioned, perceives less risk in product development projects and therefore is generally more willing to adopt NPD strategies.

Additionally, prominent directors play a complementary role of providing the volume of information that is sometimes missing when firms bridge structural holes. Management can then have a mix of “close” (from the directors) and “distant” (from the firm‘s structural holes position) information. This combination means the firm has sufficient "*search depth*" and "*search scope*" processes that are well known to be necessary for effective new product development (Katila and Ahuia, 2002).

In summary, a prominent board overcomes two limitations of the structural holes position of the firm in improving product development: firstly, a prominent board contributes by reducing search costs and risk related with "distant" information absorption; secondly, the board supplies information volume that the firm may not have or obtain from bridging structural holes.

We, therefore, expect that:

H2. *The interaction between a prominent board in the interlocking directorate network and a firm bridging structural holes position in its inter-firm relationship network is positively related to the new product development.*

3. Research method

3.1 Sample and Data

The research setting for this study is the biopharmaceutical industry. We chose this context for a number of reasons. First, biopharmaceutical companies are knowledge-based firms involved in complex R&D processes (Salman and Saives, 2005). In addition, previous literature recognizes this industry as an appropriate context for studying innovation performance (Powell et al, 1996; Rothaermel and Deeds, 2004). Moreover, the biopharmaceutical sector is characterized by long gestation periods in product development, multiple stakeholders and complex interactions among several parties that influence the innovation processes (Rothaermel, 2001; McCutchen and Swamidass, 2004). From the first stage of the drug development process to commercialization, the biopharmaceutical industry is characterized by an extensive use of inter-firm agreements (Powell et al., 1996; Billitteri et al., 2013). The biopharmaceutical industry has the highest absolute number of cooperative agreements and accounts for 20% of all strategic alliances (Rothaermel, 2001) and is thus a relevant arena for studying inter-firm relationships.

We collected data from multiple sources. We obtained data on inter-firm collaborations from the *BioWorld* database, a comprehensive database covering the global biopharmaceutical industry. *BioWorld* is used in different studies (e.g. Birch, 2008). We retrieved data on NPD from the "Biotech Products" section of the *BioWorld* database. The patenting data is retrieved from the US Patents Office database, while the director data and all the firm-attribute data are obtained from the companies' annual reports.

We built our database in several steps. The first step consisted of collecting records of inter-firm collaborations[1] between biotech[2] companies over the years 2006-2010. We obtained 1,758 agreements from 1,890 biotechnology firms. In the second step, following past research in a similar research context (Stuart et al., 2007; Phelps, 2010; Malik, 2011), we limited the sample frame to public companies to ensure the availability and reliability of firm-attribute data. Then, from the full dataset of 1,890 companies, we confined our sample to public companies, specifically 544 firms. Since we selected all the public companies in the set of 1,890 companies, no selection-bias can be associated with our sample. In the third step we matched the inter-firm collaborations data to the directors data. This step resulted in a further reduction of the sample for the following reasons. First, we included in our analysis only those firms with a significant board dimension. We therefore restricted the sample to those firms with more than 3 directors on their board. Second, we excluded firms that went public in the observation period (2006-2010). Third, we excluded firms for which we did not have full information about their directors' names. Using the above criteria we obtained a final sample of 300 public companies.

As for the interlocking director network, we obtained information on boards of directors of publicly held companies from the firms' annual reports for the years 2006-2010. We constructed the director network measure following an already applied methodology

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[1] Inter-firm collaborations in our study include: licencing agreements, acquisition/selling of R&D or manufacturing services, R&D collaborations, minority equity agreements.
[2] As biotech company we mean both pure biotechnological and biopharmaceutical.

(Omer et al., 2013). The total number of directors who served on the boards of the 300 firms in our sample during the 2006-2010 periods is 4,323. We built an annual matrix of director networks that mapped the connections between the different directors based on whether they sat on the same company board. Thus, for each firm and each year in our sample, we obtained data on the individual directors who serve on the 300 firm's board.

3.2 Measurements

3.2.1 Dependent variable

The dependent variable in this study is the new product development rate of a biotech company. We focused on NPD due to the following rationale. First, SC literature has specifically investigated the effect of network positions on patenting propensity but disregarded examining the impact of network positions on NPD. Moreover, in the biopharmaceutical context, NPD is a direct measure of how well a firm performs within a new technological paradigm in the final market. Developing new products is increasingly a focal point of competition and often requires the development and successful implementation of novel process technologies (Pisano, 1990). In the biopharmaceutical industry, introducing a new drug in the market allows the firm to gain monopoly profits for 10-15 years ensuring in this way cash, market share and getting reputation (Lieberman and Montgomery, 1988). Several scholars within this industry assume the number of new products developed as a measure of innovation performance (Rothaermel, 2001; Rothaermel and Deeds, 2004; Kalaignanam and Shankar, 2007; Bianchi et al., 2011). We operationalized the dependent variable by counting the number of new biopharmaceutical products (*New products*) a biotech firm has introduced into the market throughout 2010-2012.

Because numerous biotech companies may not have a new drug marketed every year, a 3-years window for developing new products attenuates annual fluctuations and may capture a biopharmaceutical firm's product development propensity more accurately. To assess different lag specifications between the explanatory variables (inter-firm network positions and interlocking directorate network position) and the dependent variable (new product development) we applied an approach quite adopted in literature - the dependent variable consists of observations over the 3 years (i.e. 2010-2012) following the 5 years of company-level agreement observations (2006-2010) (Bae and Gargiulo, 2004; Rothaermel and Deeds, 2004; Padula, 2008; Phelps, 2010; Vanhaverbeke et al., 2012).

3.2.2 Independent variables

To best capture the notion of prominence in our theoretical framework, we used eigenvector centrality because it is a more involved measure that utilizes the intensity of the relationships to calculate centrality (Bonacich, 1987; Ruhnau, 2000; Bonacich, 2007). We have chosen this measure of centrality for several reasons. First, eigenvector centrality considers both direct and indirect company ties, i.e. it accounts for the case in which a company is highly central with only a few ties, but is also connected to indirectly highly central firms within the network. Second, eigenvector centrality is a good measure of information volume channelled to the ego firm both from direct and indirect ties (Koka and Prescott, 2002). Third, eigenvector centrality has been associated with status accumulation in a network – a key feature of prominent positions (Shipilov and Li, 2008). Finally, in SC literature, this measure has been often related to innovation performance (Ahuja, 2000; Salman and Saives, 2005; Padula, 2008).

The second inter-firm network structure measure seeks to assess the extent to which a biopharmaceutical company does or does not bridge structural holes (*Str_holes*). We assessed the presence or the absence of structural holes in the overall network of ties among firms. We calculated this variable as one minus the firm's constraint score (in cases where constraint was non-zero) and zero for all other cases, because a score of zero in our network happens only when the firm is unconnected to others, so it has no access to structural holes. This measure of structural holes is extensively used in SC literature (Zaheer and Bell, 2005).

In order to compute the eigenvector centrality and the structural holes measures of each of the 300 firms, we used all the inter-firm collaborations within the full dataset, i.e. 1,758 agreements. We recorded each agreement in five binary $n \times n$ (one per observed years) adjacency matrixes, $\mathbf{A^t}$, where n^t is the number of firms and t is the year within the range 2006-2010. For each matrix, the term A^t_{ij} is set to 1 if the company i and company j signed an agreement in the year t, 0 otherwise. Then, by using UCINET (Borgatti et al., 2002), a network analysis program that computes network variables using dyadic data, we computed the eigenvector centrality ($Eigen^t$) and structural holes (Str_holes^t) for each firm in the network at year t. We then computed the average value of eigenvector centrality (*Eigen*) and structural holes (*Str_holes*) for each of the 300 firms over the five years of observations (2006-2010).

With regards to the interlocking directorate network centrality measure, we selected the eigenvector centrality measure because it reflects not only the number of direct links a given director has developed, but also the number of links developed by the directors to whom the given director is connected (Larcker et al., 2013; Li et al., 2013). Consequently, the bigger the eigenvector centrality measure the larger the amount of direct or indirect access and the potential quantity of information flow to or from a given director. Additionally, eigenvector centrality signals the status of an individual in networks of social relationships (Ozmel, Reuer and Gulati, 2003) a feature that, as previously explained, puts a director in a good position to filter, assess and legitimize information coming from the firm's network.

The interlocking directorate network of each of the 300 firms was computed using the 4,323 directors who serve on the boards of the 300 firms in the 2006-2010 period. We constructed five binary $n \times n$ (one per observed years) adjacency matrixes, $\mathbf{B^t}$, where n^t is the number of directors and t is the year in the interval 2006-2010. For each matrix, the term B^t_{ij}

is set to 1 if director *i* and director *j* sat on the same board in the year *t*, 0 otherwise. Then, by using the software UCINET we computed the eigenvector centrality for each director in the network at year *t*. This measure is calculated at director level; this allows us to include the inter-personal network of each individual director thus extending the analysis beyond any specific board on which they may be seating (Omer et al., 2013). Since our unit of analysis is the company, we computed the eigenvector centrality of the firm's board by averaging the eigenvector centrality of all the directors sitting on each specific company board. Thus, the variable $Interlock\_Eigen^t$ is the average (multiplied by 1,000 for scaling reasons) of the eigenvalue centrality of the interlocks of all the directors sitting on a company board for each firm at time *t.* Additionally, since we work on a 5-year observation period, we computed the average value of $Interlock\_Eigen^t$ over the five years of observations (2006-2010), and we indicate this average as *Interlock_Eigen*. Finally, since the variable *Interlock_Eigen* presents high levels of dispersion, we log-transformed the variable, and this actually improved the model fitting.

3.2.3 Control variables

We included several control variables that may impact the propensity to develop new products. First of all, we controlled for the firm's innovativeness by including a count variable of its patents received in the thirty years prior to 2010 (*patent stock*). We also included the natural logarithm of the average number of employees of each firm over the period 2006-2010 as a proxy for firm *size* (Ahuja, 2000). *R&D Expenditures* were included as the natural logarithm of average R&D expenditures in the years 2006-2010 (Bae and Gargiulo, 2004). We also controlled for *industry,* a dummy variable that indicates whether a company is a pure biotechnological or a biopharmaceutical one (Vanhaverbeke et al., 2009; Billitteri et al., 2013). Finally, we included a dummy variable (*nationality*) to distinguish between US-based and non-US biotechnology companies (1 = US firm) to control for nationality differences (Ahuja, 2000; Vanhaverbeke et al., 2012).

3.2.4. Model specification

In this study the dependent variable, *New products*, is a 'count' variable, which takes only discrete nonnegative integer values, and has possibly a large number of zero values. In order to select the best fitting approach for our count model we carried out an extensive analysis of the data. First, we took account of the general caution to adopt an OLS regression in count data. As shown in the histogram depicted in Figure 1, our dependent variable is strongly skewed to the right, so clearly OLS regression would be inappropriate.

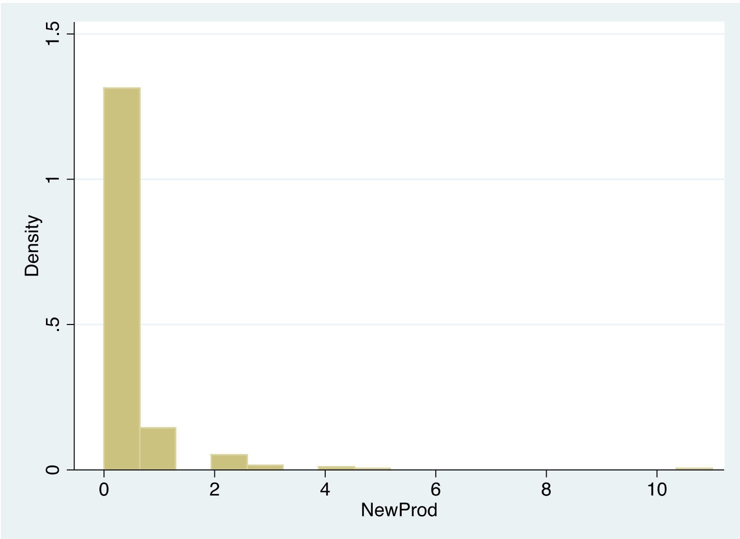

Figure 1. *New Products* variable distribution

Second, count data often follow a poisson distribution, but since over-dispersion is a possible problem with poisson regression (Hausman et al. 1984), we conducted tests to assess over-dispersion for the basic poisson specification (Cameron and Trivedi, 1986). We tested the poisson assumption (equality of mean and variance) against the negative binomial model, by using the "*gof*" command powered by STATA software that tests the Poisson goodness-of-fit. We obtained small value for chi-square in the "*gof*", meaning that the poisson distribution is a good choice. We tested each model reported in Table 2 and all models exhibit a non-significant over-dispersion[3].

In addition, we also checked for the percentage of data points of the dependent variable that take the value 0, and this percentage is quite high (85%). Theory suggests that a separate process from the count values could generate the excess zeros, so the excess zeros should be modeled independently. In our context the only phenomenon that could generate a separate process is the industry effect. Indeed, since both pharmaceutical and biotechnological companies constitute our sample, it should be possible that several biotech companies do not develop products in the time horizon (since for example they are focused on developing new patents). Thus, in order to strengthen the choice of the poisson model, we also run the Zero-Inflated Poisson (ZIP) model[4]. We test the zero-inflated model versus the standard poisson model by using the "*vuong*" command powered by STATA software. We gained a non-significant z-test, meaning that the poisson model is better.

Finally, as a further robustness check we ran a Probit regression by using the dichotomized variable of the dependent variable *New Products*. Also this model confirms the poisson results. Thus, following the results of the previous tests (*gof* and *vuong*), we can conclude in favor of the poisson specification.

4. Results

Table 1 presents the descriptive statistics and the correlation matrix of all the different variables. The correlation matrix shows that all variables have values of correlation, which should not raise multicollinearity problems among the variables. We controlled for multicollinearity problems among variables by calculating the VIF (variance inflation factor)

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[3] We have double-checked our results by using a negative binomial estimator to fit the new product models, which accommodates over-dispersed data. Using negative binomial regression (robust standard errors), all variables retain the same sign and the same significance.

[4] We excluded the zero-inflated negative binomial regression model since from the previous poisson goodness of fit test we found that poisson specification has a better model fit than the negative binomial specification.

a more advanced measure of multicollinearity than simple correlations (Stevens, 1992). As showed in Table 1, all the VIF values are below the critical level, indicating that the explanatory variables can simultaneously be included in the models (Gujarati, 1995). Finally, we also control for heteroskedasticity problems. Running the White test (White, 1980) for detecting heteroskedasticity we assessed that our data experience heteroskedasticity problems, that we have corrected using the robust standard error when running the regressions.

	Mean	*SD*	*Min*	*Max*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*VIF*
1. New products	0.27	0.91	0	11	1.00									
2. Patent stock	120.11	430.81	0	3359	0.40*	1.00								1.58
3. Size	4.48	2.43	0.28	11.5	0.28*	0.47*	1.00							1.97
4. R&D Expenditures	3.17	1.76	0	9.01	0.35*	0.49*	0.67*	1.00						2.02
5. Industry	0.61	0.48	0	1	-0.01	0.06	0.11	0.07	1.00					1.13
6. Nationality	0.36	0.48	0	1	-0.09	-0.06	-0.04	-0.06	-0.12*	1.00				1.02
7. Eigen	1.75	4.52	0	47.1	0.52*	0.31*	0.23*	0.25	-0.19*	-0.01	1.00			1.32
8. Str_holes	0.46	0.33	0	1	0.18*	0.17*	0.16*	0.21	-0.22*	0.02	0.35*	1.00		1.22
9. Interlock_Eigen	0.22	0.65	0	5.11	0.37*	0.43*	0.32*	0.32	0.02	-0.07	0.29*	0.15*	1.00	1.31

*†p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001*

Table 1. Descriptive statistics and correlation matrix

Table 2 provides an overview of the results of poisson regression analysis. We used hierarchical entry of the independent variables in the regression models. Model 1, in Table 2, is a base model in which only the controls were included. In model 2 we introduced the inter-firm network position measure *eigenvector centrality* (*Eigen*), while in Model 3 we introduced the board eigenvector centrality (*Interlock_Eigen*) of each firm. The fourth model shows the results of the first two-way interaction term, i.e. *EigenXInterlock_Eigen*.

In model 5 we introduced the second inter-firm network position *structural holes* (*Str_holes*). In model 6 we included both *structural holes* (*Str_holes*) variable and board eigenvector centrality (*Interlock_Eigen*), while in the seventh model we introduced the second two-way interaction term, i.e. *Str_holesXInterlock_Eigen*. In model 8 we entered both the inter-firm network variables, while in model 9 we entered both the inter-firm network variables and the board eigenvector centrality variable. Finally, in model 10 we reported the results when all the variables and the two interaction terms are entered simultaneously.

Since the interaction term may be highly correlated with the first-order predictor variable from which it is derived, to create all the interaction items we mean-centered the first-order variables *Eigen, Str_holes, Interlock_Eigen* to reduce any potential multicollinearity (Little et al., 2006). Considering the overall fit of each model, we observed that the introduction of the inter-firm network measures significantly improves the fit. Another significant improvement occurs with the introduction of the two interaction effects (see Table 2 below).

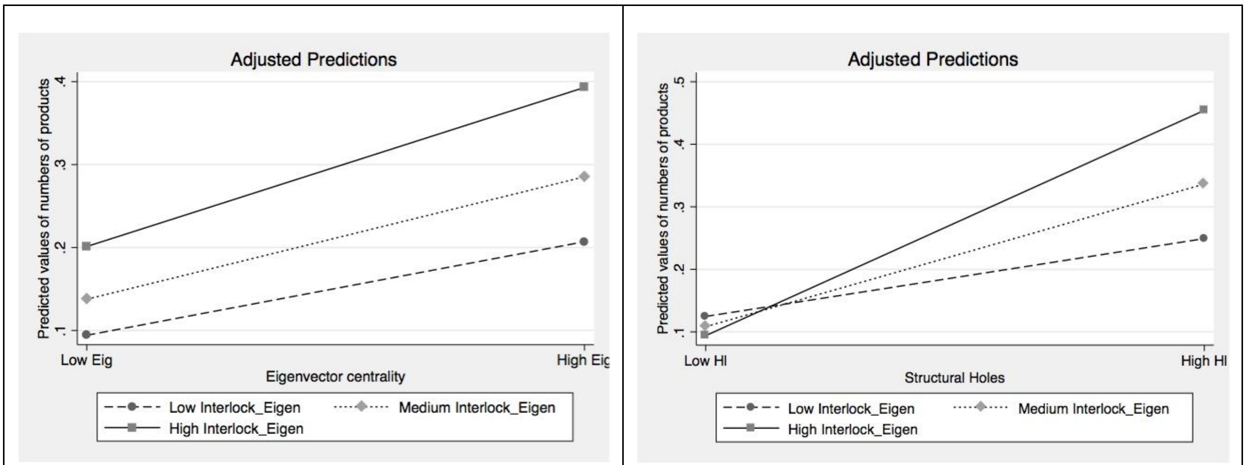
The analysis of the results of the control variables in model 1 show that *R&D expenditures* variable has a positive and significant effect on the number of new biopharmaceutical products introduced in the market. The coefficient of the variable *size* is statistically significant only in the full model 10, so no significant contribution derives from this variable on the dependent one. The *nationality* variable is negative and significant; thus US firms develop more biotech products. Finally, the coefficient of *patent stock* is significant and negative, meaning that companies in this sector seem to specialize in developing and selling patents and may neglect the development of new biopharmaceutical products.

As shown in model 2 of Table 2, the variable *Eigen* has a positive and statistically significant coefficient. This result is in line with past research that also found that a centrally located firm in its inter-firm network develops more new products. Similarly, in model 5, the variable *Str_holes* is positive though weakly statistically significant. The board centrality measure, *Interlock_Eigen,* is significant and positively related to NPD as shown in both model 3 and model 6 of Table 2. This confirms that a board that is highly connected in the interlocking directorate network increases the likely to develop new products (Wincent et al., 2010).

[Please insert Table 2 about here]

Regarding H1, we expected a positive interaction effect between inter-firm network centrality and board interlock network centrality. As shown in model 4, Table 2, the interaction term (*Eigen X Interlock_Eigen*) is positive and strongly significant as expected and so H1 is confirmed. For H2 we predicted a positive interaction effect between inter-firm structural holes position and board interlock centrality. As shown in model 5, Table 2, the interaction term (*Str_holes X Interlock_Eigen*) is positive and significant, thus confirming H2. Finally, when we added simultaneously all the interaction terms in model 10, only the interaction term *Eigen X Interlock_Eigen* remained significant and positive.

In addition, as also suggested by Jaccard and Turrisi (2003), to provide even more interesting insights on the magnitude of the moderation effects we carried out a deeper analysis whose results are shown as plots in Figures 2a and 2b.



(a) *(b)*

Figure 2. (a) Effect of *Interlock_Eigen* and *Eig* on new product development. (b) Effect of *Interlock_Eigen* and *Hl* on new product development.

Figure 2a plots the effect of the interaction on predicted values of new products of eigenvector centrality and interlock eigenvector centrality. In line with Schilling and Phelps (2007), the "Low Interlock_Eigen" line shows the slope of the effect of *Eig* on *New Products* when the value of *Interlock_Eigen* is set to one standard deviation below its mean. The "High Interlock_Eigen" line represents the effect of *Eig* on *New Products* when the value of *Interlock_Eigen* is set to one standard deviation above its mean. Finally, the "Medium Interlock_Eigen" line is the effect of *Eig* on *New Products* when the value of *Interlock_Eigen* is set to its mean. Moreover, the end points of the three lines are calculated at one standard deviation below (Low Eig) and above (High Eig) the mean of eigenvector centrality. Consistent with the results in Model 4 of Table 2, the plot of figure 1b suggests that a high level of eigenvector centrality in the inter-firm networks should be accompanied by a high level of eigenvector centrality in the interlocking directorate networks, if the objective is to accelerate the effect of firm's eigenvector centrality on the propensity to develop new products. Figure 2b plots the effect of *Structural holes* on the predicted values of new products for the same three values of interlocking eigenvector centrality calculated as before. Also for this plot, the end points of the lines are calculated at one standard deviation below (Low Hl) and above (High Hl) the mean of structural holes. Consistent with the results in Model 7 of Table 2, the plot of figure 1b shows how combining a high degree of structural holes in inter-firm network and a high level of interlocking eigenvector centrality increases the propensity to develop new products. We can conclude that the strength of the relationships (i.e. increased slope of the plots) between new product development and eigenvector centrality and new product development and structural holes are greater when *Interlock_Eigen* is high. In other words, *Interlock_Eigen* strengthens these relationships.

5. Discussions and conclusion

The present study adds to a recent trend in SC research that seeks to investigate how and why business outcomes are achieved through multiple networks (Ozmel et al, 2013; Wang et al., 2014). We do this by studying how inter-personal networks interact with inter-firm networks to achieve innovation outcomes of new product development. In particular, our study focused on how prominence in the directors' interlock network relates to information sourced from different inter-firm network positions, a mechanism that has not been explored so far in past studies. Our study explains why and how this interaction exists and the empirical analysis indicates that this interaction is useful for effective NPD.

Indeed, this is the subject of the hypotheses developed in the study - H1 and H2. Concerning H1, we found that prominent boards channel potentially valuable information to mitigate drawbacks experienced by prominent firms in inter-firm networks and in this way positively accelerate the ability to develop new products. The model results, strengthen by analysis depicted in figure 2a, seem to support our argument that a prominent board filters information flowing through the inter-firm network for its suitability, reliability and quality and does so cost effectively. Furthermore, the board itself is a source of valuable information and can fill in information gaps reducing any overspecialization risk related with prominent positions in the inter-firm network.

The second hypothesis (H2) predicted a positive interaction effect between a prominent board and the structural holes position of the firm in its inter-firm network. The results confirmed H2 and graphical illustrations in figure 2b also showed a noticeable link between prominent boards (high levels of board eigenvector centrality) and firm's structural holes position in the inter-firm network in accelerating NPD. The results support our intuition that, a prominent board plays a complementary and counteracting role when the firm exploits information from its structural holes position. A prominent board fills in information volume gaps in cases where the ego firm is rich in diverse information from its structural holes position in the network of inter-firm ties but has no sufficient internal knowledge depth to deal with such external diversity. In addition, a prominent board helps managers to reduce the information asymmetry embedded in diverse information, helping in this way to reduce the risk of processing diverse information provided by the structural holes position of the firm.

Furthermore, our results confirm the recent findings about the impact of prominent and structural holes positions in the inter-firm network on NPD. First, we find a positive impact of prominent position on NPD in line with recent findings obtained by Mazzola et al. (2015). Second, we also obtain confirmation of the positive impact of bridging structural holes in the inter-firm network on NPD. This is also in line with the theoretical framework of Mazzola et al. (2015), even though the authors do not obtain an empirical confirmation for their hypothesis. Thus, our results reinforce those of studies that have recently attempted to investigate the impact of some inter-firm network positions to NPD performance.

Moreover, this study offers important managerial implications. First, in line with previous studies (Wincent et al., 2010; Mazzola et al., 2015), we confirm the importance of networking positioning, both in the interlock directorates and inter-firm networks, for improving firm's performance such as NPD. Furthermore, our results seem to indicate that having prominent directors within the board are beneficial for prominent firms. What our study shows is that a prominent board is even more important when the firm also has prominence in the network of inter-firm ties. A prominent board's role then includes a counteracting one to mitigate possible drawbacks the firm encounters as the firm accumulates more strategic resources via its growing network. The implication is that firms have to consider carefully board compositions with regard to the total board capital available, including social capital that considers the depth and breadth of the firm's interlocking directorate network (Haynes and Hillman, 2010). Furthermore, we have discussed how interlock directorate and inter-firm networks involve persons at different levels of hierarchy and hence possibly also different source of information. From a managerial perspective this means that firms who are able to better integrate directors and product managers knowledge gain more advantage in terms of NPD performance. Thus, even if our work is not focused on analyzing the process through which firms integrate board interlock network information with inter-firm network information, it highlights the managerial importance of establishing such integration process in the firm. Some other interesting managerial implications come from the analysis of the result of the control variables. Indeed, our results confirm that in the biopharmaceutical industry firms who specialize on patent production tend to sell them as intermediate products and therefore they may neglect to develop new products (Phelps, 2010).

A further consideration concerns the interesting research field opened by the present study, i.e. the analysis of the interactions between inter-firm and inter-personal networks. There are several interesting issues that could be further investigated along this direction. One future research direction could be to evaluate the impact of the above interaction on other forms of firm performance; another path of investigation would be the analysis of the moderating role of each director's network on the relationship between inter-firm network position and innovation performance.

Finally, an additional interesting source of further investigation arises from the comparison of the magnitude and significance of the two interaction effects. Comparing Figure 2a and 2b, it becomes apparent that the influence of a prominent board is much stronger on prominent positions of the firm than on the structural holes ones. The analysis of the levels of significance in model 10 also shows that the interaction term *Str_holesXInterlock_Eigen* is no longer significant. Although this result may arise from the differences in impact of inter-firm eigenvector and structural holes on the NPD, as clearly shown in model 8 (where both *Eigen* and *Str_holes* are significant, but the first has a stronger level of significance), the result is quite unexpected. This result is surprising because, according to our theorizing a prominent board that interacts an inter-firm structural holes position has a double effect on the NPD performance, i.e. counteracting possible drawback of the inter-firm structural holes feature and a complementary role. Thus, this result merits further investigations which may involve the measurement of actual inter-tie flows.

Like all studies, this one has several limitations that further research should overcome. Firstly, network theory runs the risk of confusing network positions themselves as benefits and not as sources of benefits to focal firms (Koka and Prescott, 2002). This is because most network studies do not measure the actual benefits of network positions i.e. information or knowledge or resource flows. This is a major weakness in network literature. Although our study does not measure information flows, we move forward network research by empirically validating hypothesized flows of information benefits and how they may interact in product development. However, a deeper stage of investigation could concern how the interaction of the two flows of information actually happens in the firm. This would imply a survey analysis to understand how board directors and management exchange information coming from their respective networks.

A second limitation is relevant to the innovation performance measure we have used. Indeed, researchers often capture innovation performance with different innovation outcomes such as new developed products, number of patents and patent citations. In this paper we adopted only a NPD perspective to verify our theoretical framework. Thus, the interpretation of the results can be different in cases where other innovation measures are employed. Moreover, the same potential problem of misspecification may exist since we do not consider other perspectives of SC. In this work we addressed only one dimension of SC, i.e. structural embeddedness (measured as centrality and structural holes) and we have neglected the relational embeddedness dimension of SC - that is empirically also recognized as a significant influence of the firm's performance (Gulati, 1995; Soh, 2003). Finally, this study focuses on biopharmaceutical companies. Although the context is surely appropriate for the issues under investigations, it would be unwise to generalize the findings too broadly to other industries.

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	New products									
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*	*Model 7*	*Model 8*	*Model 9*	*Model 10*
Patent Stock	0.000138	-0.000225	-0.000463*	-0.000495*	0.0000478	-0.000134	-0.000175	-0.000260^{+}	-0.000464*	-0.000504**
	(0.000224)	(0.000163)	(0.000207)	(0.000215)	(0.000228)	(0.000245)	(0.000169)	(0.000157)	(0.000197)	(0.000175)
Size	-0.0819	0.0331	-0.0247	-0.134	-0.0702	-0.103	-0.125	0.0360	-0.0165	-0.144^{+}
	(0.189)	(0.174)	(0.106)	(0.0822)	(0.198)	(0.160)	(0.0837)	(0.176)	(0.108)	(0.0807)
R&D Expenditures	0.660*	0.481^{+}	0.539**	0.799***	0.624^{+}	0.633*	0.679***	0.470	0.521**	0.812***
	(0.320)	(0.297)	(0.186)	(0.159)	(0.337)	(0.289)	(0.125)	(0.303)	(0.190)	(0.145)
Industry	-0.290	0.401	0.322	0.258	-0.0494	-0.160	0.00840	0.536	0.420	0.396
	(0.362)	(0.407)	(0.385)	(0.374)	(0.349)	(0.371)	(0.293)	(0.380)	(0.370)	(0.347)
Nationality	-0.838*	-0.668^{+}	-0.601^{+}	-0.764*	-0.711*	-0.634^{+}	-0.443	-0.631^{+}	-0.584^{+}	-0.639^{+}
	(0.369)	(0.349)	(0.334)	(0.378)	(0.345)	(0.335)	(0.340)	(0.333)	(0.325)	(0.362)
Eigen		0.0582**	0.0566***	-0.0145				0.0533**	0.0528***	-0.0167
		(0.0188)	(0.0153)	(0.0254)				(0.0181)	(0.0152)	(0.0232)
Interlock_Eigen			0.454***	0.279*		0.396*	-0.800		0.416**	-0.117
			(0.137)	(0.119)		(0.179)	(0.634)		(0.137)	(0.306)
EigenXInterlock_Eigen				0.125***						0.108**
				(0.0320)						(0.0331)
Str_holes					1.170*	0.984^{+}	1.027^{+}	0.889^{+}	0.657	0.887^{+}
					(0.556)	(0.535)	(0.588)	(0.500)	(0.494)	(0.490)
Str_holesXInterlock_Eigen							0.747*			0.241
							(0.344)			(0.193)
Constant	-3.276***	-3.738***	-3.809***	-4.073***	-4.009***	-3.862***	-3.996***	-4.282***	-4.182***	-4.605***
	(0.625)	(0.513)	(0.479)	(0.419)	(0.654)	(0.679)	(0.586)	(0.592)	(0.585)	(0.544)
N	300	300	300	300	300	300	300	300	300	300
Wald chi2	69.63	547.80	478.48	539.35	87.23	95.12	116.52	447.56	403.71	526.51
Log pseudolikelihood	-168.96	-158.37	-150.41	-143.52	-164.60	-158.26	-147.67	-155.83	-149.10	-139.601

Robust Standard errors in parentheses $^{\dagger}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 2. Results of the Poisson analysis