Competitive Differentiation Effects of Board Network Distance*

Yang Fan†

Mu-Jeung Yang‡

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Abstract

We show that board network distance impacts competitive differentiation between indirectly connected firms. We exploit exogenous variation of director deaths to show that firms whose boards are closer in the board network, are more differentiated in terms of product segment shares, product descriptions, patenting, and patent citations. Importantly, our identification strategy exploits variation of connections to third-party firms, which are not directly affected by a director death. We provide evidence that these results are driven by information sharing, under which, closely connected firms access more credible information on potential competitors.

Keywords: Board Directors, Product Differentiation, Innovation

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†Assistant Professor, Department of Economics, Colby College, Email: *yffan@colby.edu*

‡Corresponding author: Assistant Professor, Department of Economics, University of Oklahoma, Email: *mjyang@ou.edu*

1. Introduction

Corporate competitive differentiation can be defined as the differentiation of firms along the two dimensions of product market space and technology space, see Bloom, Schankerman and Van Reenen, 2013. A variety of recent empirical work has shown that corporate competitive differentiation matters for our understanding of risk premia and diversification discounts (Litov, Moreton and Zenger, 2012), the nature and extent of R&D spillovers (Bloom, Schankerman and Van Reenen, 2013), M&A performance (Hoberg and Phillips, 2010), corporate financial policies (Hoberg, Phillips and Prabhala, 2012), and industry selection of conglomerates (Hoberg and Phillips, 2016). Yet, what drives corporate competitive differentiation in the first place is still poorly understood.

At the same time, boards of directors are the very nerve center of corporate decision-making, suggesting that they also play a pivotal role for competitive differentiation. However, much of the current empirical literature only focuses on "board interlocks", or overlapping directors, see Fracassi, 2017; Geng, Hau, Michaely and Nguyen, 2021; Cabezon and Hoberg, 2023. This traditional approach neglects the possibility of indirect board network effects, in which inconspicuous indirect connections to other firms can influence competitive differentiation at the focal firm.[1] To our knowledge, ours is the first study to provide evidence that indirect connections matter for corporate competitive differentiation. Specifically, we ask two related questions. First, what is the impact of board network distance, defined as the shortest path to connect two firms through the board network, on corporate competitive differentiation? Second, what is the mechanism driving how board network distance impacts competitive differentiation?

The first main question presents a challenging identification problem, as argued for example, by Hermalin and Weisbach, 2001. The reason is that public firms typically endogenously select directors for their boards. To address this endogeneity issue, we build on an approach by Fracassi, 2017, who used exogenous variation of unexpected director deaths as an instrument for

[1] Another potential issue with the traditional focus on board interlocks, is that direct competitors are legally prohibited by the Clayton Act of 1914 to share any directors. However, in practice, not many public companies are in violation of the Clayton Act partly due to the vague definition of "direct competition" in the case law surrounding the act, which typically is narrower than the 2-digit SIC industries we consider here. Additionally, there are rules exempting lines of businesses that fall below 4% of corporate sales, see https://www.ftc.gov/news-events/blogs/competition-matters/2017/01/have-plan-comply-bar-horizontal-interlocks.

changes in board interlocks. We begin by demonstrating that there are no significant differences across a variety of observable characteristics between firms that experience a director death during the periods preceding the director death and firms that do not experience a director death (often called a “balance test”. This balance test suggests that the variation of director deaths is indeed as good as random. We then extend Fracassi’s approach and calculate implied exogenous increases in board network distance, resulting from unexpected director deaths, which enables us to estimate the effect of indirect board connections. Importantly, this change in board network distance is calculated on an “immediate impact” basis, which excludes potentially endogenous effects of how past directors are replaced. We then analyze the impact of increasing board network distance on competitive differentiation along its two dimensions of product market and technology space. For this purpose, we bring together measures for competitive differentiation from different sources. First, we provide two measures of product market differentiation. Our first measure is based on the similarities in revenue distribution across industries in Compustat, following a similar approach by Litov et al., 2012 and Bloom et al., 2013. The second measure is based on product description similarity in regulatory filings, constructed by Hoberg & Phillips, 2016. Second, we measure technology space differentiation by the similarity in technology class distribution of patent applications by firms, using patenting data from the USPTO, as well as a measure of patent citation flows from Kogan, Papanikolaoi, Seru, and Stoffman, 2017.

Prior work, mostly focusing on direct board connections or social ties, has established that directly connected firms are more similar along important dimensions, such as corporate financial policies (Fracassi, 2017; Shue, 2013), acquisitions (Haunschild, 1993, 1994) and organizational choices, such as multidivisional form (Palmer, Jennings, and Zhou, 1993). In contrast, we find that companies which are closer in the board network, tend to be more differentiated instead of more similar. In particular, our results show that an exogenous decrease in board network distance causes product market differentiation and patenting differentiation to increase, not to decrease. Companies closer in the board network are more differentiated, while companies that are further away in the board network are more similar to each other. Our emphasis on indirect board network connections further strengthens our identification argument, as one potential concern with using director deaths as exogenous variation is that they trigger “board chaos” in the spirit of (Nguyen & Nielsen, 2010) and therefore have their own effect on firms. However, our baseline analysis excludes companies that share a common director and only focuses on corporations that do not share a director, but their implied distance in the board network increases as result of an unexpected director death by a third-party company.

In the context of our second main question, we provide evidence that sheds light on a mechanism that could plausibly drive our main result: information sharing. Under information sharing, firms that are closer in the board network receive more credible information on the competitive differentiation of their potential competitors, which they might unilaterally use to competitively differentiate. Under this information sharing hypothesis, firms more distant to each other, obtain less credible information on each other's competitive positioning and therefore end up more similar. But this raises the question: If information sharing is beneficial to disclosing firms, why wouldn't all firms simply disclose such information publicly instead of using director networks?

To investigate this question, we build on the idea that the value of information transmitted through board networks should depend on the availability of public information about a firm: The more available public information there is about a firm, the lower the value of information about the firm that is obtained through board networks should be. We proxy public information about connected firms with a measure of firm opacity based on equity analyst disagreement about future earnings. We find that for more opaque firms, competitive differentiation effects of board network distance are stronger.

Related Literature

This study contributes to at least four main strands of literature. First, our work is related to empirical work on endogenous product market differentiation and its implications for corporate decisions, as in Hoberg and Phillips, 2010, 2012, 2016a, 2016b, Litov et al. 2012 and Bloom et al. 2013. Much of this literature takes product market differentiation as given and explores the implications of differentiation on stock returns and diversification premia (Litov et al. 2012), M&A performance (Hoberg and Phillips, 2010), corporate financial policies (Hoberg, Phillips and Prabhala, 2012), industry selection choices of conglomerates (Hoberg and Phillips, 2016b) and R&D spillovers (Bloom, Schankerman and Van Reenen, 2013). Among the exceptions is Hoberg and Phillips, 2016a, who analyze the relationship between text-based product differentiation measures and R&D and advertising investments, Fan et al. (2022), which focus on technological uniqueness and Cabezon and Hoberg, which we discuss below. Importantly none of these studies analyzes indirect board network connections as determinant of competitive differentiation.

Second, our work is complementary to recent work on the effects of direct board connections (overlapping directors) on corporate product differentiation and technology adoption (Cabezon and Hoberg, 2023; Geng et al., 2022). Both studies focus on close competitors with shared directors and exploit state-level changes in Corporate Opportunity Waivers (COWs) as natural experiment. We share with these studies the emphasis on information sharing as a potential mechanism to explain corporate differentiation. However, in contrast to these studies, we conceptually emphasize the effect of indirect board network connections which reinforces the importance of information sharing between connections that are not as obvious. Empirically, we exploit the impact of director deaths on indirect connections as a novel identification strategy and document the quasi-random nature of director deaths. Additionally, we push the analysis of information sharing effects beyond close competitors to all publicly traded firms, which can potentially become competitors through endogenous changes in differentiation.

Third, our work also complements existing work on the influence of social networks on corporate finance, as in Fracassi, 2017; Fracassi and Tate, 2012; Shue, 2013; Nguyen, 2012; Bouwman, 2011; Chen, Dyball and Wright, 2009, David and Greve, 1997 and Haunschild, 1993. However, while much of this literature focuses on corporate policies of interlocked firms, we generalize this notion and emphasize the role of indirect network effects while providing additional evidence on whether results are driven by collusion or information sharing through board networks.

Finally, this study contributes to a large and expanding literature on firm linkages, such as supply-chain links (Barrot and Sauvagnat (2016), Ersahin et al. (2022)), common banking connections (Saidi and Streitz (2021)), and common ownership (Azar et al., 2014; Backus et al., 2021; Koch et al. (2021), Lewellen and Lowry (2021)). Broadly, the literature on supply-chain links and banking concentration emphasizes the downstream effects of factor market disruptions, while there is a debate about the effects of common ownership on corporate competition. We complement these efforts by documenting the importance of inconspicuous indirect board network connections on corporate competition and believe that future work can explore potential interactions between, for example board network distance effects and factor market shocks.

2. Data and Measures

2.1 Sample and Data Collection

The sample of firms used in this study includes the Compustat list of S&P 1,500 public companies in the United States between 2003 and 2013. We matched this sample of firms to BoardEx, which provides data on board and director characteristics.[2] Using BoardEx's composition of directors on a board for a given year, we use overlaps of the same director across multiple firms to initially determine the boards that are interlocked and then the minimum number of directors needed to indirectly connect all remaining pairs of S&P 1,500 boards.

Our competitive differentiation measures come from a variety of sources. Two different sources of data are used to calculate and determine the relative product market space positioning of each firm-pair. First, we use Compustat Historical Product Segment data to obtain the firm's market segments and the annual sales of the firms in each of these segments. This is used to determine the degree of product segment similarity between two firms. Second, the product description similarity data is obtained from (Hoberg & Phillips, 2010, 2016). The data is based on web crawling and text parsing algorithms that process the text in the business descriptions of 10-K annual filings on the SEC Edgar website from 1996 to 2015. Since the product descriptions are legally required to be accurate, they should sufficiently represent the managers insight to their own firm's product lines.

Our measurements of technological space differentiation also come from two main sources. Patent class and patent-citation data is obtained from USPTO (NBER U.S. Patent Citations Data File) and Kogan et al., 2017. These datasets contain the patent number, patent application date, the technology class that is associated with the patent, and the subsequent citing patents from 2000-2010. We consider patent applications as opposed to patent grants as patent granting procedures may include timing lags that firms are not able to control for. We also consider a patent-application window of three years since firms may submit patent applications for many patents one year but no patents for the next few years.[3]

[2] We apply the standard practice of converting the dates into calendar years. For report dates that occur in July or later, we classify information regarding the firm's board to that same year. For report dates that occur in June or before, we classify that as the firm's board data for the previous year.
[3] See Lerner & Seru, 2021 for an in-depth discussion on these patent adjustment methodologies.

2.2 Measurement of Board Network Distance

When a director simultaneously sits on the board of both firms, the two firms are said to be "interlocked" or "directly connected" and the distance between these two firms is 1, the smallest possible distance. Figure 1 provides an example of how a director can connect firms. In the example, solid lines represent a director that is shared by the firm-pair. Each director is unique to that firm-pair.

[Figure 1]

Network distance describes the closeness between two firms, measured by the minimum number of directors needed to connect two firms. Companies that do not share directors can be indirectly connected through third-party boards and their closeness is determined by the number of third-party boards needed to connect the two firms. In Figure 1, the network distance between Apple and Nordstrom is 5 since five different directors are needed connect Apple to Nordstrom (solid lines). Importantly, our baseline analysis only focuses on indirectly connected firms and will exclude firms with overlapping directors, such as Walmart and American Express.

Our empirical analysis will place special emphasis on cases when connections change, resulting in changes to the network distance between firms. Suppose initially, a director connects Wal-Mart and American Express (dotted line), implying that the network distance between Nordstrom and Apple is 3. As long as Wal-Mart and American Express remain connected, the shortest distance between Apple and Nordstrom is 3, even though an alternative path linking Apple and Nordstrom through Procter & Gamble and General Electric exists. However, if the connection between American Express and Wal-Mart is dissolved, this increases the network distance between Nordstrom and Apple from 3 to 5 (or a change of network distance of 2). This calculation of changes of board network distance in this example is done on an "immediate impact" basis: one can recalculate the board network distance for any path that was disconnected by using the current network. This is the main way we will calculate changes board network distances in response to our instrument of director deaths.

Panel A of Table 1 summarizes the shortest network distance between pairs of firms in the sample. To connect the average firm pair within the S&P 1,500, 4.7 directors are needed. Larger firms with larger boards tend to be more closely connected, on average. Figure 2 is a histogram of network distances for firm-pairs in our sample.[4]

[Table 1, Panel A], [Figure 2]

2.3 Measures of Competitive Differentiation

2.3.1 Product Segment Similarity

Suppose two firms i and j, each sell into n product market segments. The basic premise of the product segment similarity measure is that the competitive intensity between two firms can be measured by how similar their sales distributions are across these *n* product market segments. The more similar these distributions are, the more intense the competition is likely to be between them.

Formally, let firm i's sales share at time t in n segments be a $1xN$ vector, $F_{i,t} = \{F_{1,t}, F_{2,t}, F_{3,t}, \dots F_{n,t}\}$. Similarly, let firm j's sales share at time t in n segments also be a $1xN$ vector, $F_{j,t} = \{F_{1,t}, F_{2,t}, F_{3,t}, \dots F_{n,t}\}$. Then, the product segment similarity score between firms i and j at time *t* is (2):

$$PSS_{ij,t} = \frac{F_i F_j'}{(F_i F_i')^{\frac{1}{2}}\left(F_j F_j'\right)^{\frac{1}{2}}} \tag{1}$$

The product segment similarity score is between 0 and 1 where larger scores closer to 1 indicate greater sales similarity and therefore more competitive intensity while score closer to 0 indicates more differentiation and therefore less competition.

2.3.2 Product Description Similarity

One possible concern with our sales segment similarity measure may be that abated competition may not be observed if product market segments are too broadly defined. Therefore, we also utilize the Hoberg-Philips Text-Based product description similarity score (similarity score constructed by comparing product descriptions for each firm) as an alternative measurement of product differentiation. If two managerial descriptions from the firm's annual 10-K contain similar verbiage, the products produced by the two firms are more likely to be similar as well, indicating greater competitive intensity between the firms. Therefore, product description similarity scores

[4] About a third of firm boards cannot be reached by other firm boards even though board data exists for both firms. The vast majority these unconnectable pairs includes a firm that is a member of the S&P 600 index.

for each firm-pair that are close to 1, indicate more similar product descriptions and less differentiation, while firm-pairs that report scores that are closer to zero indicate products that are very differently described and more differentiated.

2.3.3 Patenting Similarity

We adapt a patenting similarity score by Jaffe, 1986 where technological similarity between two firms is based on the technology class of their patents. The firm's distribution of patents into these technology classes describes the average technological positioning of firms in a technology space. Changes in the distribution of patents in technology classes over time, can be mapped into changes in technological similarity between two firms.

Suppose two firms i and j, patent into k technology classes. Formally, let firms i's patent share (in a technology class) at time t in k technology classes be a $1xK$ vector, $T_{i,t} = \{T_{1,t}, T_{2,t}, T_{3,t}, \dots T_{k,t}\}$. Similarly, firm j's patent share at time t in k technology classes also be a $1xK$ vector, $T_{j,t} = \{T_{1,t}, T_{2,t}, T_{3,t}, \dots T_{k,t}\}$. Then, the technology similarity score between firms i and j is (3):

$$TSS_{ij,t} = \frac{T_i T_j'}{(T_i T_i')^{\frac{1}{2}} (T_j T_j')^{\frac{1}{2}}} \qquad (2)$$

Similar to the product segment similarity score for two firms, this technology score is between 0 and 1, where a technology score that is closer to 1, means that the two firms are likely to be less technologically differentiated. Examining patenting distribution across time allow us to track how technological positioning may alter following distance-changing events.

2.3.4 Patent Citations

The technological similarity score describes the average positioning of innovations by firms, but it is silent on the direction of information flows. However, future innovations often build on past innovations and the implied information flow from knowledge about past innovations to new innovations can be captured in patent citations (Trajtenberg, 1990).

To measure information flows on innovation between two firms, we consider how patent citation numbers change over time. If firm A and B operate in a similar technological space, they can improve on each other's existing patents, by applying for new patents. However, to demonstrate that their new improvements sufficiently warrant a new patent, a patent examiner will consider other patents to look closely at. These other patents are frequently disclosed ahead of time or cited by the inventor to ensure the patent examiner closely considers these patents or other patents may be found by the examiner herself as part of the examination process. Additionally, it is also generally in the best interest of the inventor to reveal all similar patents to the examiner to avoid patent infringement litigation.

Summary statistics for all measures of competitive differentiation is provided in Panel B of Table 1.

[Table 1, Panel B]

Panel B of Table 1 shows that the average competitive differentiation across firm-pairs is relatively low, which is unsurprising, as public firms are active in very different markets and industries.

3. Empirical Methodology

This section will detail empirical issues and our identification strategy.

3.1 Control Variables

Given that firm size may be related to diversification in industry and product offerings (Aron, 1988), relative firm size between a pair of firms might imply less differentiation by random chance (henceforth “size effects”). For example, two very diversified firms by definition, operate in a variety of sectors and the chance that they might therefore overlap in a higher number of segments is higher, as opposed to very focused firms. Second, similar arguments can also be made about firm-pairs in which both firms have a large number of directors. We will use a number of variables to control for potential size effects directly. This set of control variables includes: (1) total number of directors across a firm-pair to control for board size effects, (2) total number of industry segments across a firm-pair to control for the effect that more diversified pairs are more likely to be similar to each other and (3) relative firm size measured by total assets to control for the fact that firms of different sizes might be expected to be very different in their competitive positioning.

3.2 Endogeneity Problem and Identification

Our baseline empirical strategy is to use first differences to remove time-invariant, pair-specific fixed effects, which removes a variety of unobservable confounders that might affect a firm-pair. But, even after using first-differencing to remove time-invariant pair effects and using a number of proxy variables to control for potential size effects, there are still at least two distinct endogeneity problems that will tend to bias the results towards finding that more closely connected firms tend to me more similar.

The first endogeneity issue is the presence of "peer imitation effects", i.e. the possibility that firms might select to appoint directors to learn from and imitate other firms, see (Davis & Greve, 1997; Shue, 2013; Fracassi, 2017). For example, in 2010, Steve Reinemund, who was then a director of American Express, joined the board of Walmart. Both firms had no similarity, as Walmart is primarily active in retail, while American Express is a financial services firm. Yet, only 2 years later, both firms rolled out a joint venture called "Bluebird", which is an alternative to traditional bank checking accounts. Walmart therefore became more similar to American Express by entering financial services.[5] Other research has confirmed that peer imitation matters especially for overlapping directors. Tuscke et al., 2014 documented, within a sample of German firms, that direct board network connections led to the entry into the same Eastern European markets. Additionally, recent work by Cabezon and Hoberg, 2023 finds that product description similarity increases among close competitors in industries with high director overlap. Cabezon and Hoberg, 2023 provide direct evidence on imitation by tracking key technology terms in 10-K text.[6]

A second endogeneity problem is a form of endogenous selection and is discussed in the theoretical literature on identification in social networks, such as Manski, 1993; see also Bramoullé, Djebbari, and Fortin, 2009 and Goldsmith-Pinkham and Imbens, 2013. Social network analysis faces a version of Manski's "Reflection Problem", as corporate directors and therefore, connecting peer firms are endogenously chosen. As a result, any unobserved common shock within a set of connected firms will create a correlation between policies, that are unlikely to be solely effects of board network connections. Similar to peer imitation effects, Manski's Reflection Problem will tend to induce closely connected firms to have similar corporate policies.

[5] Note that in this example it is not important whether Walmart had initially planned to enter financial services and therefore hired Reinemund as director, or whether Walmart hired Reinemund he brought up the idea of a joint venture with American Express. In both cases, there will be a correlation of overlapping directors and product segment similarity.

[6] Cabezon and Hoberg, 2023 contend that in industries with a many overlapping directors, that "total product market differentiation in the industry actually decreases significantly."

The ideal solution to address these endogeneity problems is randomized assignment of firms into groups as argued by Angrist, 2014. In our context this would be equivalent to random assignment of the degree of distance that corresponds to board network distance. We exploit unexpected director deaths as quasi-random variation, which provides exogenous shocks in our setting. Public firms have corporate bylaws in place that stipulate how planned director departures are handled.[7] For unplanned departures such as a director death, the board seat generally remains vacant until the next shareholder meeting. We use director death data from BoardEx and categorize the deaths as unexpected by verifying each using public announcements, news articles and regulatory statements. We identify approximately 300 instances of unexpected deaths in our sample. Details on our data construction of unexpected director deaths can be found in Appendix A1. Although the use of unexpected director deaths is well-established in the literature, e.g. Fracassi, 2017, there are potential arguments for why the exclusion restriction for overlapping directors might fail. One plausible failure might be that director deaths trigger "board chaos", which directly affects firms. To address this potential violation of the exclusion restriction, we analyze indirect network effects. To understand this strategy, consider the companies in Figure 1. While Wal-Mart and American Express are directly connected through a director, Apple and Nordstrom are only indirectly connected. If the link between Wal-Mart and American Express is disconnected, this will increase the board network distance between Apple and Nordstrom from 3 to 5. Since the boards of the indirectly connected firms Apple and Nordstrom are not directly affected by the unexpected death of the director that Wal-Mart and American Express shared, there will be no direct impact of the director death on these boards and therefore no violation of our exclusion restriction.

A separate identification concern is that the choice of whether to reconnect after a director death can be endogenous. To address this issue, we quantify the exogenous variation in board network distance by calculating the implied distance change at the time of the director death, also called "Board Network Distance-II" for "Immediate Impact". In other words, for each firm we calculate the minimum distance to every other firm in the board network, with and without the

[7] In general, for planned vacancies, the nomination committee puts forth nominees to be voted upon at the company's next annual shareholder meeting. The outgoing director stays on during this transition process to ensure a smooth transition.

dead director, and use the difference between these two distances as our measure of exogenous change in board network distance.

Let X denote board network distance and δ_{ij} a dummy for a director death in the firm pair ij at time t. Formally, the indirect network effect identification strategy leads to the following first stage:

$$\Delta X_{kl\neq ij,t} = \alpha_1 \cdot \delta_{ij,t} + \Delta Controls_{kl\neq ij,t-1} + D_t + D_g + D_s + error \tag{3}$$

where the index $kl \neq ij$ captures the fact that we analyze firm-pairs (k,l) which are not the firm-pair (i,j) directly affected by the death of a shared director. In addition to the control variables we discussed in section 3.1, we also include a full set of year fixed effects (D_t), (HQ) state fixed effects (D_g) and industry fixed effects (D_s) and alternatively even industry-by-year $(D_s \times D_t)$ and state-by-year $(D_g \times D_t)$ fixed effects.

We will then analyze the impact of this change in the shortest path on firm behavior of the indirectly affect firm-pair:[8]

$$\Delta \ln(1 + y_{kl\neq ij,t}) = \beta_1 \cdot \Delta X_{kl\neq ij,t} + \Delta Controls_{kl\neq ij,t-1} + D_t + D_g + D_s + error \tag{4}$$

Where, y denotes similarity measures in terms of product market and technology space. We use log differences to estimate percentage changes. Throughout our analysis, we estimate all specifications in first-differences to control for firm-pair fixed effects and cluster standard errors at the firm-pair level. Simulation results by Jennings et al., 2022 suggest that over-differencing can sometimes lead to false positive results, so they suggest "extreme caution in circumstances when fixed effects absorb more than 90% of the variation in the independent variable of interest." In our case, pair fixed effects explain only around 60% of the variation in the dependent variables, so we stay well clear of the threshold suggested by Jennings et al., 2022.

As an alternative to the pair-level specification in (3) and (4) we also consider firm-level specifications, in which we focus on particular focal firms, denoted by k so that $[k]l \neq ij$ denotes the set of firms l that firm k is indirectly connected to and with which it does not share a director death.

[8] Although sequentially discussed, (3) and (4) are jointly estimated.

$$\Delta X_{[\boldsymbol{k}]l\neq ij,t} = \alpha_1 \cdot \delta_{ij,t} + \Delta Controls_{[\boldsymbol{k}]l\neq ij,t-1} + D_t \times D_l + error \tag{5}$$

This firm-level specification allows us to control for a full set of firm-by-year fixed effects $(D_t \times D_l)$ for all of the firms that focal firm k is connected to.

$$\Delta \ln\left(1 + y_{[\boldsymbol{k}]l\neq ij,t}\right) = \beta_1 \cdot \Delta X_{[\boldsymbol{k}]l\neq ij,t} + \Delta Controls_{[\boldsymbol{k}]l\neq ij,t-1} + D_t \times D_l + error \tag{4}$$

3.3 Balance Test of Director Death Instrument

To support the credibility of our measurement of unexpected director deaths, we provide a balance test in this section. The main idea of a balance test is that under random assignment of the instrument and during the pre-treatment periods, means of observable variables should be the same for treatment and control groups. The treatment group in our context are firms that experienced an unexpected director death, while the control group are firms that never experienced a director death. Any finding of significant differences in pre-treatment period means would suggest that the director deaths are not necessarily unexpected and might therefore not be randomly assigned. Importantly, since all our main analysis removes permanent pairwise fixed effects, the correct means to compare are first differences of variables, as such first differences remove permanent fixed effects as well. The variables we use in these balance test are all main dependent variables and control variables discussed in sections 3.1 and 3.2.

[Table 2]

Table 2 shows means for treatment and control groups, as well as t-values for tests of statistically significant differences. Standard errors for the t-tests are clustered on the firm level. As Table 2 shows, only 1 out of 12 outcomes displays a statistically significant differences in average changes. Additionally, none of the four main outcome variables of competitive differentiation is significantly different in the years before direct deaths, when comparing treatment and control groups.

4. Competitive Differentiation Results

4.1 Event Study Analysis

As a complement to our regression analysis, we also present an event study analysis on the competitive differentiation effects of board network distance changes due to unexpected director deaths. We conduct our event analysis on the firm-pair level, for only indirectly connected firm pairs. The events we analyze are director deaths and we center our analysis around $t = 0$, which is defined as the year of a director death. The panels in Figure 3 measure event time on the horizontal axis, which is defined as the years before and after the director deaths in our sample. Treatment firm-pairs are defined as all indirectly connected pairs for which an unexpected director death at $t = 0$ increases board network distance. The death event increases the distance in the board network between the firms. Control firm-pairs are indirectly connected pairs not affected by director deaths. We deliberately do not use any additional control variables or matching procedures at this step to showcase how our baseline results are already foreshadowed even with this simple approach.

We use the 3-year horizon before and after the respective director deaths to analyze how director deaths influence competitive differentiation. As dependent variables, we use the cumulative changes relative to event time zero in competitive similarity, either measured by product segment similarity, product description similarity, patenting similarity, or patent citations. Average treatment effects are calculated by averaging cumulated changes in competitive differentiation across treatment-pairs and control-pairs each year and then taking the difference of the averages.

[Figure 3]

As the panels in Figure 3 show, along all of the competitive similarity measures, we see an increase in similarity in response to an increase in board network distance in the wake of unexpected director deaths. The impact of director deaths on our measures of technological competition (Panels C and D) are consistent with the results from the product market space (Panels A and B). As Figure 3 Panel C shows, firm-pairs with increased board network distance, as a result of director deaths, experience less differentiation in terms of patenting technology classes. At the same time, patent citations (Figure 3 Panel D) increase, as one would expect if treated firm-pairs start to use more similar technologies, relative to control firm-pairs. All panels of Figure 3 highlight the fact that the competitive differentiation effects are not transient in their levels but are persistent.

Although suggestive, this event-study type analysis has several potential shortcomings. First, since we focus on treated firm-pairs and control-pairs only, we do not exploit the full pair-level data across all years, which substantially reduces statistical power. Second, the event plots deliberately did not make use of any control variables or matching procedures to make treatment and control groups more comparable. This has the downside that firm-pairs are not necessarily comparable in terms of relative size, industries, geographies etc. Third, we averaged over all possible treatments, but the strength of effects might depend on how much network distance changed as a result of director deaths.

4.2 Board Network Distance and Competitive Differentiation Effects

[Table 3]

Table 3 reports our basic OLS specification, including controls for the size effects discussed in section 3.1. Panel A suggest that there is a strong positive correlation between more closely connected boards and greater levels of competitive differentiation, specifically that boards that become closer in network distance to one another, tend to be more differentiated in terms of products and technologies. It should be noted that these OLS results by themselves are already strong evidence for the competitive differentiation effects of board network distance, since they control for firm-pair-level fixed effects. Additionally, Panel B shows that these competitive differentiation effects of board network proximity can also be found in firm-level regressions with a full set of firm-by-year fixed effects for non-focal, connected firms. Although the coefficients are not statistically significant for product segment similarity and product description similarity, they are significant for the technology measures. However, that these OLS correlations between competitive positioning and board network distance should not be interpreted in causal manner, as they are still likely to suffer from endogeneity due to either peer imitation effects or Manski's reflection problem.

[Table 4]

The first stage results in columns 1, 4 and 6 of Table 4 show that director deaths increase board network distance across indirectly connected firms by 1.2 on average. This effect is comparable to the standard deviation of board network distance among S&P 1500 firms reported in Table 1 and are slightly larger than the standard deviation of annual changes in board network distance of 0.8. Furthermore, the immediate impact changes in board network distance in response to unexpected director deaths are similar in magnitude to changes in board network distance after taking director replacements into account. For this comparison, consider columns 1, 4 and 6 of Panel B in Table 4 with the corresponding columns in Panel A of Table 5.

Our IV strategy results from equations (3) and (4) start with Panel A of Table 4. Firm-pairs that are not directly affected by a director death, but still see an increase in their board network distance as a result of a director death become less differentiated over time.

A number of features reassure us that our baseline results are robust. First, OLS and IV results both exhibit the same sign and are mostly statistically significant. Furthermore, the magnitude of our IV results is much larger than the OLS results, as would be expected if our IV strategy is successful in separating out peer imitation effects and endogeneity through Manski's reflection problem (both of which imply more similarity of connected firms) from actual causal effects of board network distance. In Appendix A2, we discuss how measurement error and overdifferencing are likely to strongly attenuate OLS estimates and we show that for realistic values of measurement error, the inflation of IV relative to OLS is much lower. Second, these results hold across four different measures of competitive positioning as can be seen in Table 3 and Table 4. Hence, the competitive differentiation effects of board networks hold not just for segment sales, but also for business descriptions and even patenting patterns and patent citations. Third, Panel B of Table 4 uses a full set of industry-by-time and state-by-time fixed effects to control for any unobserved state-specific time trends (e.g. the staggered introduction of COWs as in Geng et al., 2022; Cabezon and Hoberg, 2023) and any industry-specific time trends (e.g. differential industry time trends in antitrust enforcement or differences in rise of common ownership as in Azar et al., 2018). Although it is not surprising that our IV results are robust to controlling for this host of omitted variables, it is reassuring. Fourth, Panel C of Table 4 alternatively provides IV estimates for firm-level regressions with a full set of firm-by-year fixed effects for connected firms. Again, estimated effects are consistent with competitive differentiation for more closely (indirectly) connected firms.

When evaluating the credibility of the causal effects of board network distance on competitive differentiation we offer here, it is useful to consider potential violations of exclusion restrictions in these indirect network specifications. Such violations of the exclusion restrictions would occur if disconnections between directly connected firm-pairs (i, j) would directly affect the competitive positioning among only indirectly connected firm-pairs (k, l). One possibility of such a failure of exclusion are common demand shocks that make similar positioning among a pair (k, l) more attractive, are also correlated with disconnections at the firm-pair (i, j). However, such an effect is unlikely, especially since director deaths are unexpected and therefore unrelated to market opportunities at unrelated third-party firms (k, l). The exclusion restriction might also fail due to unobserved characteristics among indirectly connected firm-pairs (k, l) that tend to select into indirect links that also have a high likelihood of disconnection. However, several arguments suggest that this type of selection is very unlikely. Note that these unobserved characteristics of the indirectly connected firm-pair (k, l) have to be time-varying factors such as expectations, as all our specifications directly control for firm-pair fixed effects. Furthermore, if director deaths are unexpected for directly affected firms, they are even harder to forecast by firms that are only indirectly affected. Additionally, even if a director death at one firm is forecastable, bounded rationality would suggest that it is implausibly challenging to predict these deaths for all possible indirectly connected links through the board director network. Finally, even if firms would not be subject to bounded rationality and fully rationally choose directors, it seems implausible that they would aim to select into networks that are more likely to be fragile, as building and maintaining connections is costly. As these considerations illustrate, explanations that render identification in our indirect network specification invalid are mostly implausible.

4.3 Quantitative Interpretation of IV Estimates

To analyze the quantitative implications of our IV estimates, we provide two sets of comparison benchmarks. On the one hand, we calculate the effect of a one standard deviation change in board network distance on competitive differentiation and contrast it with the standard deviation of competitive differentiation variables. This comparison highlights the magnitude of board network effects on pair-level competitive differentiation. On the other hand, we contrast our IV estimates with other determinants of competitive differentiation from the literature. Although most effects in the literature are strictly speaking not comparable, this benchmarking can still help to put board network effects into perspective.

Combining IV estimates from Table 4 with summary statistics from Table 1, we calculate that a one standard deviation increase in board network distance, increases product segment similarity by 0.05% $(0.0005 = 0.000654 \cdot 0.806)$, which corresponds to a 4.85% change in product segment similarity, relative to the standard deviation of annual (log) changes in product segment similarity of 0.0109 according to Table 1. This is a quantitatively modest effect, which is unsurprising given the fact that we focus on indirect connections. Similarly, a one standard deviation increase in board network distance increases product description similarity by 2.73% of the annual standard deviation of product description similarity $\left(= \frac{0.000116 \cdot 0.806}{0.0034}\right)$ and technological similarity by 8.03% $\left(= \frac{0.00173 \cdot 0.806}{0.017}\right)$. These magnitudes confirm that our IV estimates have quantitatively meaningful implications for competitive differentiation.

Before we report how the quantitative magnitudes of board network distance compare to other determinants from the literature, it is worthwhile to point out potential caveats. Studies in the literature differ in terms of whether and what type of identification strategy is used. While studies, such as Hoberg and Phillips, 2016; Oemichen et al., 2020 only provide OLS estimates, other work, such as Geng et al., 2022, Cabezon and Hoberg, 2023 and Fan et al., 2023 use natural experiments that differ from ours. As is well known since Angrist and Imbens, 1996, different IVs will elicit responses from different sets of "compliers", which implies that estimated causal effects will differ, if the underlying treatment effect magnitudes differ across firms, as is likely. Additionally, with the exception of Geng et al., 2022, most other studies do not provide firm pair-level estimates, but aggregate pair-level variation to the firm-level, often within an industry. On the one hand, our pair-level estimates are not strictly speaking comparable to these estimates, because firm-level differences in competitive differentiation reflect firm-level factors as well as pair-level factors. On the other hand, dependent variables are often very close in terms of measurement to the "cosine similarity" measures we use and often only differ in what the vector of product segment revenues or patenting is compared to. For example, Oemichen et al., 2020 and Fan et al., 2023 compare the vector of product segment revenue or patents to industry averages (called "centroids") instead of comparing these vectors to all possible connected pairs. To make our pair-level estimates comparable to firm-level estimates, we multiply them by the average number of directors on firms, which is around 9 for S&P 1,500 companies.[9]

[9] Studies typically differ in whether their main independent variable is a dummy or is continuous. Whenever studies use a continuous variable, we compare the quantitative implications of a one standard deviation change, while we compare a one standard deviation change in board network distance with the dummy effect if independent variables are binary.

For our product segment similarity results, we compare our estimates with Oehmichen et al., 2020, who show that dedicated, long-term oriented investors and board independence is significantly correlated with product segment similarity, relative to average peer firms. Their estimates imply one standard deviation effects of 0.0304 for investor dedication and 0.021 for board independence. The effect of board network distance on product segment similarity is therefore 15.57% $\left(=\frac{0.000527\cdot 9}{0.0304}\right)$ of the investor dedication effect and 22.28% of the board independence effect $\left(=\frac{0.000527\cdot 9}{0.0212}\right)$.

For product description similarity, Hoberg and Phillips, 2016 report that firms that do exhibit advertising or R&D expenditures at all, tend to exhibit lower total product similarity, defined as the sum of pairwise similarity within a narrow industry. Our IV estimates suggest that a one standard deviation board network distance change is about 2.27% of the estimate for advertising $\left(=\frac{0.00093\cdot 9}{|0.037|}\right)$. Cabezon and Hoberg, 2023 show that COWs have a direct impact on total product description similarity, which is about 45 times higher than our estimates for the impact of indirect board network distance on product description similarity $\left(=\frac{0.00093\cdot 9}{0.038}\right)$. Geng et al., 2022 provide estimates of director overlap of close competitors, instrumented with COWs, on product segment similarity. Their impact estimates are over 18,000 times larger than the effect of indirect board network distance $\left(=\frac{0.00093}{|1.745|}\right)$.

For technological similarity, we compare our estimates to Fan et al., 2023, who provide estimates of four IVs on technological similarity relative to peer firms. These include changes in state-level R&D tax credits as in Bloom et al., 2013; changes in distance to USPTO offices in the wake legislation expanding the number of patent offices; patent expirations of close competitors and changes in patenting of industry peers that opens up technological niches (centroid changes). The effect of board network distance on technological similarity is about 7.65% of the effect of state-level R&D tax credits $\left(=\frac{0.001394\cdot 9}{|0.164|}\right)$, about 19.7% of the effect of changes in USPTO distance $\left(=\frac{0.001394\cdot 9}{0.063}\right)$, about 17.83% of the effect of patent expiration of close competitors $\left(=\frac{0.001394\cdot 9}{|0.07|}\right)$ and 2.56% of the effect of industry centroid changes $\left(=\frac{0.001394\cdot 9}{0.49}\right)$.

Overall, these comparisons to the existing literature suggest that the causal effect of board network distance is quantitatively smaller than many effects estimated in the literature, but still economically meaningful.

5. Robustness and Extensions

5.1 Board Network Distance with Endogenous Director Replacement

Our baseline board network distance measure focused on the immediate impact of director deaths on distance, without taking into account the distances after director replacement. Hypothetically, if a director dies, she could be replaced by another director linking the same set of firms. However, for most directors it is unlikely to find another individual with exactly the same type of experience and connections, as well as the same fit with the firm seeking to replace the director. As a result, even if an overlapping director for an individual firm pair could be easily replace, the same will not be true for all firm pairs. As a result, director death will still have important consequences for the type of indirect board network connection our analysis is focused on.

[Table 5, Panel A]

In support of this conceptual point, we re-run our analysis of the director death-IV in Panel A of Table 5. The board network distance measure used in Table 5 just computes board network distance after a director death using the network distance taking into account the replacing director. Comparing the estimates in Panel A of Table 5 with the results of Panel B of Table 4 highlights the quantitative similarity of all effects, even though the product similarity results are somewhat larger in the robustness check.

5.2 Competitive Differentiation Effects as Function of Initial Board Network Distance

One implication of information sharing in board networks is that firms that are closer in the board network will receive more reliable information about their mutual competitive positioning than firms that are further apart. A main reason of this differentiated information sharing is communication frictions: information on firms that are more distant in the board network will become noisier and less reliable.[10] We therefore analyze the causal estimates of board network

[10] This point is summarized by Ghosh and Rosenkopf, 2015: "It is a basic premise of communication theory that there is some loss of fidelity along a link when information flows between two nodes. The analog to interpersonal communication is that even though two people seek to share information, some of it may be misunderstood as a result of unintentional error".

distance on competitive differentiation, as a function of initial distance in Panel B of Table 5. The panel splits our IV results into pairs that are close (as defined by a network distance at or below the median distance of 4. In contrast initially distant pairs are defined to have a distance of at least 5.

[Table 5, Panel B]

Table 5, Panel B shows that generally the competitive differentiation effects of board network distance tend to be smaller in magnitude for pairs that start out to be further apart. These results are consistent with an information sharing view of board networks.

5.3 Competitive Differentiation Effects as Function of Industry Board Network Density

Another possible implication of information sharing is that the overall density of board network connections within the industry might matter. However, the theoretical predictions for this external variable can be theoretically ambiguous. On the one hand, more closely connected industries might imply that there is a lot of information sharing, which in turn leads to each individual link being less important. The prediction of this hypothesis would be that the causal impact of board network distance on competitive differentiation should be weaker in densely connected industries and should be stronger in sparsely connected industries. On the other hand, norms supporting information sharing might be more common in densely connected industries, which might lead to each individual link to be more effective in transmitting information. In this case, one would expect the competitive differentiation effects of board network distance to be stronger in densely connected industries. We quantify the density of connections using the average distance across firms in the same industry and then consider industries above the median density as densely connected, while below median industries are defined as sparsely connected.

[Table 5, Panel C]

The results are reported in Panel C of Table 5. It shows that for product segment similarity, as well as for product description similarity, causal effects of board network distance are indeed stronger in densely connected industries. However, surprisingly the same is not true for our measures of technological differentiation. Both patent similarity and patent citation exhibit stronger board network distance effects in more sparsely connected industries. This might potentially indicate that different types of information (e.g. market opportunities as opposed to technological opportunities) is differently affected by the presence of a dense network of director links. However, a deeper analysis of what drives this difference is beyond the scope of this study and therefore left for future research.

5.4. Evidence on Information Sharing as the Mechanism driving Competitive Differentiation Effects of Board Network Distance

Central to the test of information sharing is the idea that firm-pairs with closer board network distance, exhibit more flows of credible information on competitive positioning among each other. The basic idea of this section is that the incremental value of private information that flows through the board network is low, if there is already a lot of available public information about the firms, i.e. they are already very transparent. In other words, information flowing through the board network should have its biggest impact on competitive differentiation if it flows among relatively opaque firms, which fail to communicate effectively with the public.

To test this, we construct measures of public firm opacity, based on analyst data from I/B/E/S, see Appendix A3 for details. We construct measures of earnings forecast dispersion across analysts to capture the idea that less consensus among analysts is indicative of higher degrees of firm opacity.[11] We then measure the (relative) opacity of a firm-pair, by taking the product of the firm-specific opacity variables. If information sharing can explain competitive differentiation effects of board network distance, then competitive differentiation effects of closely connected firms should be stronger for firm-pairs that are relatively opaque.

[Table 6]

Table 6 confirms that these predictions of the information sharing hypothesis indeed hold in the data. Firm-pairs that are relatively opaque see stronger competitive differentiation effects in response to increased board network proximity.

7. Conclusion

This study is the first to establish causal evidence for the impact of board network distance on competitive differentiation among US corporations. Our key finding is that decreased board

[11] Using analysts' earnings per share forecast dispersion as a proxy for analyst disagreement follows from a large literature including Diether, Malloy, and Scherbina, 2002 and Johnson, 2004. For example, Johnson, 2004 attributes differences in firm EPS forecast dispersion to differences in the firm's information setting (parameter risk).

network distance, as measured by closer connections of board directors across firms, leads to more competitive differentiation. Furthermore, we document evidence supporting the view that these competitive differentiation effects are driven by information sharing, under which board networks enable firms to obtain credible information on potential competitor's product and technology choices, which enables them in turn to avoid wasteful duplication.

Our main competitive differentiation effects of board network distance support the view that firms avoid wasteful duplication of investments and effort based on information exchange through board networks. This paper suggests at least two major avenues for future research. First, building on our analysis here, the use of data on board networks together with indirect network effect identification strategies, offers a variety of opportunities to estimate the causal effects of strategy decision-making and information exchange by directors on corporate policies. Second, a deeper analysis of the determinants of competitive positioning promises to uncover more insights on what is driving corporate policies and corporate innovation decisions.

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Figure 1

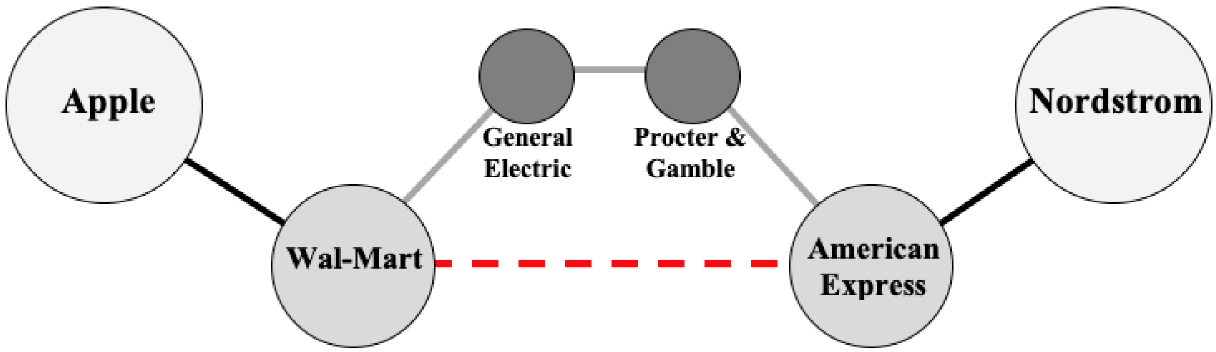


Figure 1: Illustration of how board network distance is measured across companies. Links connecting companies are shared directors on company boards. Distance measures in the board network are minimum distances between two companies, also called shortest path or the geodesic.

Figure 2

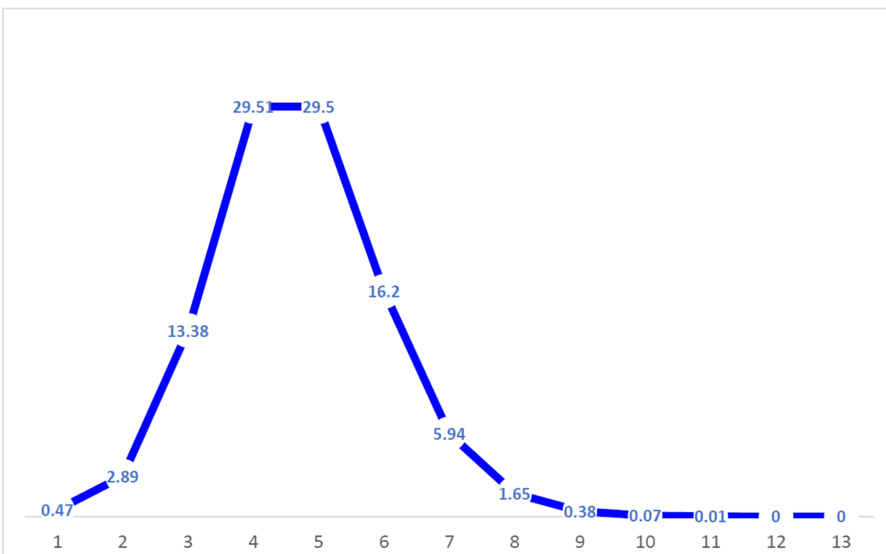
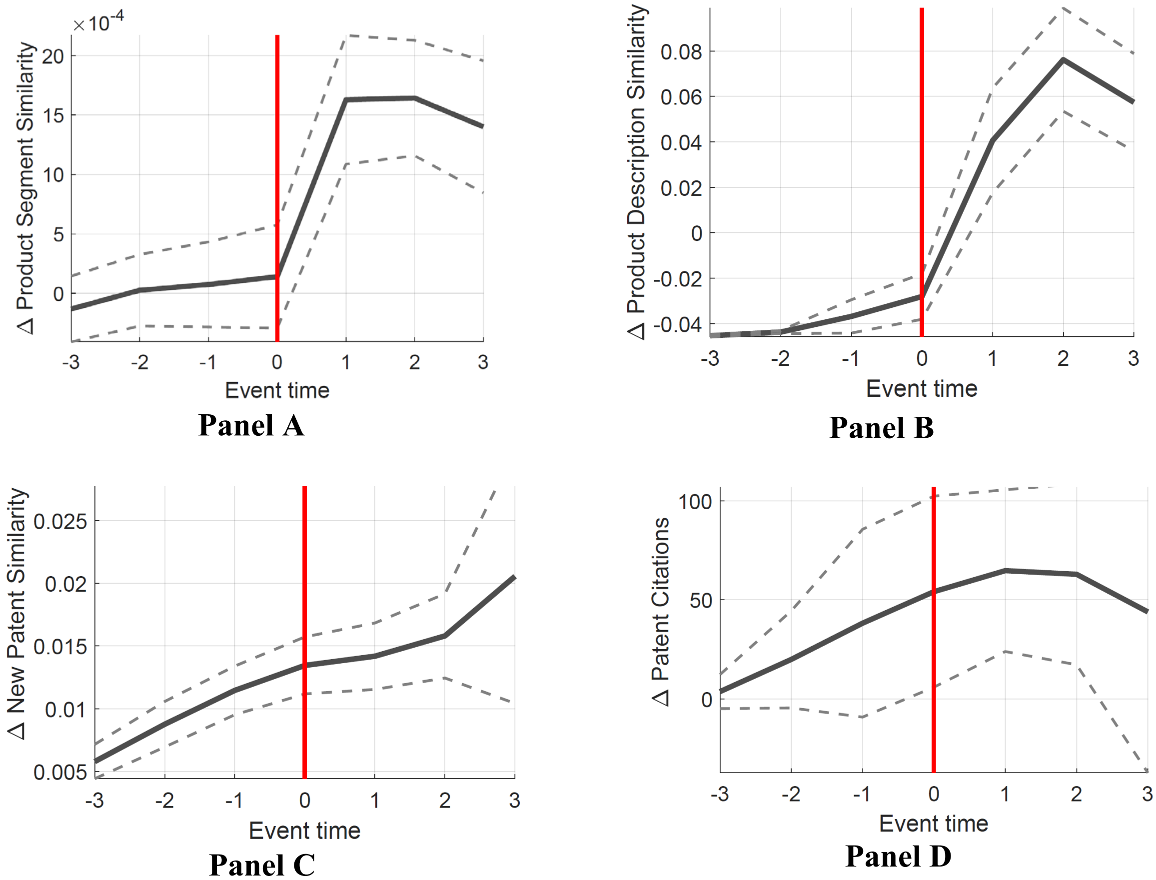


Figure 2: Histogram of network distance (shortest path) between S&P1,500 firm-pairs in the sample from 2003-2013. Network distance refers to the number of different corporate boards that separate two firms, so more closely connected firm-pairs exhibit closer board network distance. A network distance of 1 means that two firms are directly connected or interlocked by a shared director. The average network distance between all firm-pairs in the sample is 4.68 while the median is 5.

Figure 3



Notes: Cumulative average competitive differentiation effects in event time. Treatment firm-pairs are defined as pairs that are indirectly connected and for which a director death at t=0 increases board network distance. Control firm-pairs are indirectly connected pairs that do not experience an increase in board network distance during the event window, which covers 3 years before to 3 years after director deaths. Cumulative average treatment effects are calculated by averaging competitive differentiation across treatment-pairs and control-pairs, cumulating changes relative to event time zero (director death year) and then taking the difference of the cumulative averages. Figures display 95% confidence bands.

Table 1: Summary Statistics

	Panel A: Summary Statistics (2007)		
Board Network Distance Measures	**Frequency (Firm-Pairs)**	**Average Board Distance**	**Standard Deviation**
Board Network Distance (Level - All Firm-Pairs)	977,138	4.417	1.219
Board Network Distance (Change - All Firm-Pairs)	1,308,735	-0.0146	0.866
Board Network Distance (Level - Indirect Firm-Pairs)	972,724	4.433	1.200
Board Network Distance (Change - Indirect Firm-Pairs)	1,303,556	-0.0131	0.864
Immediate Impact Distance (Level - Indirect Firm-Pairs)	971,497	4.433	1.203
Immediate Impact Distance (Change - Indirect Firm-Pairs)	839,267	0.0141	0.827
	Panel B: (Pairwise) Competitive Positioning		
Variable	**Obs**	**Mean**	**Std.**
Product Segment Similarity (PSS)	6,586,897	0.00677	0.0745
Product Description Similarity (PDS)	6,586,897	0.00145	0.0107
Patent Similarity Score (TS)	461,366	0.0171	0.0643
Patent Citations	92,183	44.907	651.692
ΔProduct Segment Similarity	6,586,897	0.69314	0.0109
ΔProduct Description Similarity	6,586,897	0.36791	0.0034
ΔPatent Similarity	461,366	0.6926	0.0174
ΔPatent Citations	92,183	22.529	8.401

Notes: Panel A: *Board network distance* is the minimum number of shared corporate directors needed to connect two boards so more closely connected firm-pairs exhibit closer or less board network distance. A network distance of 1 means that two firms are directly connected through a shared director, the minimum possible network distance between two boards. *Frequency (Firm Pairs)* refers to the number of unique firm-pairs. Panel B: *Product Segment Similarity Score* refers to the similarity in industry revenue shares between firms. *Product Description Similarity Score* is the Hoberg-Philips text-based network industry classifications from firm 10-K product descriptions. *Patent Similarity Score* is based on the similarity of technology classes of patents by firms. *Patent Citations* is based on the number of patents that one firm cites the other firm each year. Both the patent similarity score and the patent citation score use a rolling three-year calculation of patents. Δ*Product Segment Similarity,* Δ*Product Description Similarity,* Δ*Patent Similarity,* and Δ*Patent Citations* refer to the log-changes of the respective variables. Δ*Board network distance-II (Immediate Impact)* uses implied board network distance change at time of director death for all pairs affected by director deaths.

Table 2: Balance Tests for Director Death as Random Treatment

	No Director Death Sample				Director Death Sample				Diff
	mean	SE	Obs	Firms	mean	SE	Obs	Firms	t-stat
%ΔAssets	0.134	0.006	14,587	1,994	0.065	0.041	208	50	1.67
%ΔR&D	0.150	0.017	5,923	813	0.091	0.098	126	26	0.57
%ΔRevenues	0.120	0.008	14,587	1,994	0.089	0.052	208	50	0.59
%ΔNumber of Product Segments	0.012	0.002	11,382	1,583	0.040	0.012	176	44	-2.41
%ΔNumber of Board External Connections	0.058	0.004	14,556	1,971	0.043	0.030	202	44	0.50
%ΔNumber of Directors	0.005	0.001	14,557	1,972	0.014	0.005	202	44	-1.16
%ΔNumber of Director External Connections	0.051	0.004	14,556	1,971	0.032	0.027	202	44	0.71
ΔPSS	-0.0002	0.0001	13,325	1,782	-0.0001	0.0010	197	43	-0.14
ΔPDS	0.0000	0.0000	14,599	1,997	0.0000	0.0002	208	50	0.00
ΔTS	-0.0070	0.0002	839	193	-0.0008	0.0002	88	23	0.24
ΔPatent Citations	-0.727	0.205	1,421	321	-1.604	0.664	158	34	1.26
ΔBoard Network Distance	-0.003	0.004	14,599	1,997	-0.004	0.024	208	50	0.03

Notes: For firms that experience a director death, we summarize all years *prior* to the year of the director death. *%ΔAssets*, *%ΔR&D*, and *%ΔRevenue* measure the average annual percentage change in assets, R&D expenditures, respectively. *%ΔNumber of Product Segments* measures the change in Compustat Product Segments that the firm reports sales to. *%ΔNumber of Board External Connections*, *%ΔNumber of Directors*, and *%ΔNumber of Director External Connections* measures the change in connectness of the boards. The *Number of Board External Connections* is the total number of other boards that the focal board is connected to through its directors. The *Number of Directors* is the number of corporate directors on the board or the board size. The *Number of Director External Connections* is the average number of outside boards that each director concurrently sits on. Δ*PSS*, Δ*PDS*, Δ*TS*, and Δ*Patent Citations* are the change in the competitive positioning metrics averaged across firms. Δ*Board Network Distance* is the average change in board distance between firms. The difference in means of the two sets of firms are compared and the t-statistic is adjusted for clustering at the firm-level.

Table 3: Baseline OLS

	Panel A: Pair-level, only indirect pairs			
	(1)	(2)	(3)	(4)
	ΔProduct Segment Similarity	**ΔProduct Description Similarity**	**ΔPatent Similarity**	**ΔPatent Citations**
ΔBoard Network Distance-II	0.0000141*	0.00000661***	0.0000123	3.187***
	(0.00000559)	(0.00000182)	(0.0000349)	(0.0359)
Additional controls	See table notes			
Fixed Effects	Year, Industry, State			
Observations	6586897	6586897	461366	92184

	Panel B: Firm-level, only indirect pairs			
	(1)	(2)	(3)	(4)
Board Network Distance-II	0.00000908	0.00000209	0.00226***	1.349***
	(0.00000903)	(0.00000294)	(0.000274)	(0.0773)
Additional controls	See table notes			
Fixed Effects	(Indirectly connected) Firm-by-Year			
Observations	5532763	5532763	640086	91843

Notes: Panel A (top) examines the changes across indirectly connected firm-pairs. Panel B (bottom) examines firm-level regressions of a focal firm to all indirectly connected firms. *Board network distance-II (Immediate Impact)* uses implied board network distance change at time of director death for all pairs affected by director deaths. *Product Segment Similarity* is measured using industry revenue similarity of firms in Compustat segments. *Product Description Similarity* is text similarity in 10-K filings, constructed by Hoberg and Phillips. *Patent Similarity* is measured using the similarity of the NBER technology classes of firm patents. *Patent Citations* captures the degree of citation of patents across firms. Additional controls for all specifications include: *(Δ)# of Directors* is the (change in) total number of directors. *(Δ)# of Ind. Segments* is the (change in) total number of industry segments and relative assets as measure of relative size. Additional controls for columns (3) and (4) of both panels include: *(Δ)# XRD Intensity* is the relative R&D intensity (technology space). Robust standard errors are clustered at the firm-pair level (Panel A) at connected firm level in (Panel B) and are in parenthesis.

Table 4: IV Estimates

Panel A: Pair-level, only indirect pairs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	1st Stage	*2nd Stage*	*2nd Stage*	*1st Stage*	*2nd Stage*	*1st Stage*	*2nd Stage*
	ΔBoard Network Distance-II	**ΔProduct Segment Similarity**	**ΔProduct Description Similarity**	**ΔBoard Network Distance-II**	**ΔPatent Similarity**	**ΔBoard Network Distance-II**	**ΔPatent Citations**
(Indirect) Director Death	1.189***			1.221***		1.268***	
	(0.00268)			(0.0147)		(0.0276)	
ΔBoard Network Distance-II		0.000654***	0.000116***		0.00173**		2.522***
		(0.0000688)	(0.0000131)		(0.000543)		(0.506)
Additional controls	See table notes						
Fixed Effects	Year, Industry, State						
Cragg-Donald F-statistic		76315	76315		3857.45		1405.66
Kleibergen-Paap p-value		0.0000	0.0000		0.0000		0.0000
Observations	6,586,897	6,586,897	6,586,897	461,366	461,366	92,157	92,157

Panel B: Pair-level, only indirect pairs (finer FEs)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(Indirect) Director Death	1.175***			1.191***		1.242***	
	(0.00274)			(0.0143)		(0.0280)	
ΔBoard Network Distance-II		0.000675***	0.000119***		0.00178**		2.412***
		(0.0000698)	(0.0000133)		(0.000557)		(0.508)
Additional controls	See table notes						
Fixed Effects	Industry-by-Year, State-by-Year						
Cragg-Donald F-statistic		76427.62	76427.62		3840.39		1393.19
Kleibergen-Paap p-value		0.0000	0.0000		0.0000		0.0000
Observations	6,586,897	6,586,897	6,586,897	461,366	461,366	92,157	92,157

Panel C: Firm-level, only indirectly connected

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(Indirect) Director Death	0.713***			0.702***		0.702***	
	(0.0164)			(0.0600)		(0.0719)	
ΔBoard Network Distance-II		0.00124***	0.000236***		0.00341**		3.448*
		(0.000151)	(0.0000272)		(0.00129)		(1.350)
Additional controls	See table notes						
Fixed Effects	(Indirectly connected) Firm-by-Year FE						
Cragg-Donald F-statistic		18339.14	18339.14		1347.29		343.73
Kleibergen-Paap p-value		0.0000	0.0000		0.0451		0.0000
Observations	5532763	5532763	5532763	640086	640086	91843	91843

Notes: Panel A, B**:** First difference IV specifications to control for pair fixed effects. First stage uses indirect director deaths for exogenous variations in board network distance where a director death increases the network distance between two indirectly connected firms. *Board network distance-II (Immediate Impact)* uses implied board network distance change at time of director death for all pairs affected by director deaths. *Product Segment Similarity* is measured using industry revenue similarity of firms in Compustat segments. *Product Description Similarity* is text similarity in 10-K filings, constructed by Hoberg and Phillips. *Patent Similarity* is measured using the similarity of the NBER technology classes of firm patents. *Patent Citations* captures the degree of citation of patents across firms. Additional controls for all specifications include: (Δ)*# of Directors* is the (change in) total number of directors. *(Δ)# of Ind. Segments* is the (change in) total number of industry segments and *relative assets* as measure of relative size. Additional controls for columns (3) and (4) of both panels include: *(Δ)# XRD Intensity* is the relative R&D intensity (technology space). Robust standard errors are clustered at the firm level and in parenthesis. Panel C: Sample consists of focal firms that are indirectly connected to other firms. Otherwise all definitions for Panels A,B apply. Standard errors are clustered at the indirectly connected firm level and are displayed in parentheses.

Table 5: Robustness and Extensions

Panel A: Pair-level, indirect pairs, with director replacement

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	1st Stage	*2nd Stage*	*2nd Stage*	*1st Stage*	*2nd Stage*	*1st Stage*	*2nd Stage*
	ΔBoard Network Distance-II	**ΔProduct Segment Similarity**	**ΔProduct Description Similarity**	**ΔBoard Network Distance-II**	**ΔPatent Similarity**	**ΔBoard Network Distance-II**	**ΔPatent Citations**
(Indirect) Director Death	1.178***			1.245***		1.294***	
	(0.00264)			(0.0128)		(0.0235)	
ΔBoard Network Distance		0.000674***	0.000117***		0.00168**		2.318***
		(0.0000697)	(0.0000133)		(0.000550)		(0.492)
Additional controls	See table notes						
Fixed Effects	Industry-by-Year, State-by-Year						
Cragg-Donald F-statistic		77394.03	77394.03		3935.53		1403.59
Kleibergen-Paap p-value		0.0000	0.0000		0.0000		0.0000
Observations	6,586,897	6,586,897	6,586,897	461,366	461,366	92,157	92,157

Panel B: Pair-level, only indirect pairs and initial distance

	Distance at most 4				*Distance 5 or more*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	2nd Stage	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*
	ΔProduct Segment Similarity	**ΔProduct Description Similarity**	**ΔPatent Similarity**	**ΔPatent Citations**	**ΔProduct Segment Similarity**	**ΔProduct Description Similarity**	**ΔPatent Similarity**	**ΔPatent Citations**
ΔBoard Network Distance-II	0.00134***	0.000203***	0.00311**	4.124**	0.000483***	0.0000977***	0.00247*	4.120
	(0.000197)	(0.0000395)	(0.00114)	(1.425)	(0.0000672)	(0.0000160)	(0.00110)	(3.264)
Additional controls	See table notes							
Fixed Effects	Industry-by-Year, State-by-Year							
Cragg-Donald F-statistic	18320.94	18320.94	1017.78	311.94	40194.78	40194.78	773.95	28.54
Kleibergen-Paap p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	3641875	3641875	322520	67694	2944505	2944505	138655	9523

Panel C: Pair-level, only indirect pairs and density of connections

	Densly connected industries				*Sparsly connected industries*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	2nd Stage	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*	*2nd Stage*
	ΔProduct Segment Similarity	**ΔProduct Description Similarity**	**ΔPatent Similarity**	**ΔPatent Citations**	**ΔProduct Segment Similarity**	**ΔProduct Description Similarity**	**ΔPatent Similarity**	**ΔPatent Citations**
ΔBoard Network Distance-II	0.00166***	0.000188***	0.00145	3.196	0.000471***	0.000134***	0.00657**	6.032*
	(0.000242)	(0.0000393)	(0.00106)	(3.354)	(0.0000974)	(0.0000332)	(0.00213)	(2.931)
Additional controls	See table notes							
Fixed Effects	Industry-by-Year, State-by-Year							
Cragg-Donald F-statistic	16236.71	16236.71	388.43	66.77	17834.84	17834.84	536.52	73.03
Kleibergen-Paap p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	1727215	1727215	133081	23738	1574836	1574836	97867	17094

Notes: First difference IV specifications to control for pair fixed effects. First stage uses indirect director deaths for exogenous variations in board network distance where a director death increases the network distance between two indirectly connected firms. *Board network distance-II (Immediate Impact)* uses implied board network distance change at time of director death for all pairs affected by director deaths. *Product Segment Similarity* is measured using industry revenue similarity of firms in Compustat segments. *Product Description Similarity* is text similarity in 10-K filings, constructed by Hoberg and Phillips. *Patent Similarity* is measured using the similarity of the NBER technology classes of firm patents. *Patent Citations* captures the degree of citation of patents across firms. Additional controls for all specifications include: *(Δ)# of Directors* is the (change in) total number of directors. *(Δ)# of Ind. Segments* is the (change in) total number of industry segments and *relative assets* as measure of relative size. Additional controls for columns (5) and (7) of panel A and (3), (4), (7), (8) of panels B and C: *(Δ)# XRD Intensity* is the relative R&D intensity (technology space). Robust standard errors are clustered at the firm level and in parenthesis.

Table 6: Information sharing and Opacity

	1st Stage	*1st Stage*	*2nd Stage*	*2nd Stage*
	ΔBoard Network Distance-II	**ΔBoard Network Distance-II X Opacity**	**ΔProduct Segment Similarity**	**ΔProduct Description Similarity**
(Indirect) Director Death	0.943***	-0.742***		
	(0.0181)	(0.159)		
Opacity X (Indirect) Director Death	-0.408***	1.489***		
	(0.0189)	(0.161)		
ΔBoard Network Distance-II			0.000244*	0.0000989***
			(0.000115)	(0.0000262)
Opacity X ΔBoard Network Distance-II			0.00120***	0.000164***
			(0.000181)	(0.0000346)
(Relative) Opacity	1.084***	0.434***	-0.00143***	-0.000217***
	(0.000977)	(0.00602)	(0.000179)	(0.0000332)
Additional controls	See table notes			
Fixed Effects	Industry-by-Year, State-by-Year			
Cragg-Donald F-statistic			7568.642	7568.642
Kleibergen-Paap p-value			0.0000	0.0000
Observations	5367698	5367698	5367698	5367698

Notes: First difference IV specifications to control for pair fixed effects. First stage uses *indirect* director deaths for exogenous variations in board network distance where a director death indirectly increases the network distance between two firm. *Board network distance-II (Immediate Impact)* uses implied board network distance change at time of director death for all pairs affected by director deaths. *Product Segment Similarity* is measured using industry revenue similarity of firms in Compustat segments. (*Relative) Opacity* is measured using the dispersion in analysts' forecasts of earnings per share. Additional controls include the change in *total number of directors*, *change in total number of industry segments* and *change in relative assets*. Robust standard errors are clustered at the firm level and in parenthesis.