Interlocking directorates, competition, and innovation

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10-10-2023

[LATEST VERSION]

Abstract

Holding concurrent seats on boards of rival firms, 'horizontal directors' dampen competition and improve firm performance. In the cross-section of public US firms, losing an interlock with a competitor decreases returns by 3 percentage points. I propose a mechanism of market segmentation where horizontal directors steer firms away from fierce direct competition. Using data on patenting, I show that horizontal interlocks help firms maintain distance in the competitive space and reduce redundancy, increasing innovation quantity and quality by 15 to 35 percent.

1 Introduction

Eric,

I would be very pleased if your recruiting department would stop doing this.

Thanks,
Steve

— Jobs, Steve. "Google Recruiting from Apple." Email to Eric Schmidt. 07 March 2007.

Directors who hold concurrent board appointments across multiple firms, or "busy" directors, create informal ties between firms - commonly known as interlocks. Despite being

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heavily criticized as inefficient, disloyal, undemocratic, and "the root of many evils" (Brandeis 1914), interlocking directorates have been very common among US firms throughout the 20^{th} century, and remained so to this day. Little has changed since the 1930s, when 90% of the 250 largest corporations were interlocked with each other (Means et al. 1939): today, more than 20% of directors in S&P1500 companies hold concurrent board seats, and nearly 85% of S&P1500 firms share at least one director with other S&P1500 firms (Hauser 2018). This is not a coincidence. Busy directors offer extensive connections and greater expertise which are valuable to companies. Renowned and well-connected directors bring prestige to the firm, a positive signal to investors, broader perspective of the business environment, and act as a conduit of relevant information through their relationships with financiers, clients, suppliers, or rivals. Their seats come at a cost, however, as the effort and attention of busy directors are inevitably lower and conflicts of interest may pose a genuine concern.

In this paper I highlight a special case - the horizontal interlock, where a director holds multiple appointments within an industry, and study its effect on firm performance. A horizontal director provides perhaps a more extreme trade-off balance to the firm than a non-horizontal does. On the one hand, horizontal directors bring deeper industry-specific expertise, and are better informed of the institutional details, trends, and prospects. They also offer an invaluable information channel, which could encourage efficient collaboration, synergistic mergers, or tacit collusion. On the other hand, the potential conflict of interests is exacerbated. Since competition imposes negative externalities on stakeholders of rival firms, a horizontal director has less to gain from aggressive product-market strategies than a director with no stake in the industry. Internalizing this, he would be incentivized to steer firms towards a less aggressive stance, thus limiting the extent of competition: beating your rivals is not as appealing when you are on their payroll.

This question is important to our understanding of market competition, investment and innovation. A recent high-profile example that illustrates this is the 2009 Department of Justice (DoJ) investigation into several tech companies, who allegedly colluded to refrain from poaching each other's employees.[1] The DoJ raised concerns that the directorate interlock across Apple and Google, as illustrated in Figure 1, played a key role enabling noncompetitive behavior. The investigation uncovered email exchanges between Apple's CEO Steve Jobs and Google's chairman and CEO Eric Schmidt, who concurrently held seats on both boards, as did another director - Arthur Levinson. In that exchange, Jobs asked Schmidt to have Google's recruiting department cease its attempts to hire Apple's engineers. The horizontal interlock through Schmidt was central in communicating both Apple's complaint to Google, and Google's report of the internal investigation back to Apple, enforcing alleged collusion. As relief, the DoJ requested the court to restrain the firms from agreements that restrict competition, and eventually a settlement was reached that prohibits the companies from engaging in anticompetitive no-solicitation agreements, and resolved the department's antitrust concerns. The interlock was also severed after Schmidt resigned from the board of Apple in August 2009, and Levinson resigned from the board of Google two months later.

While resignations are a commonly sought remedy, the mere severance of interlocks may

[1] See the DoJ complaint, US v. Adobe Systems Inc., et al., and 2010 settlement; and the subsequent class action, Hariharan v. Adobe Systems Inc., et al., and 2015 settlement.

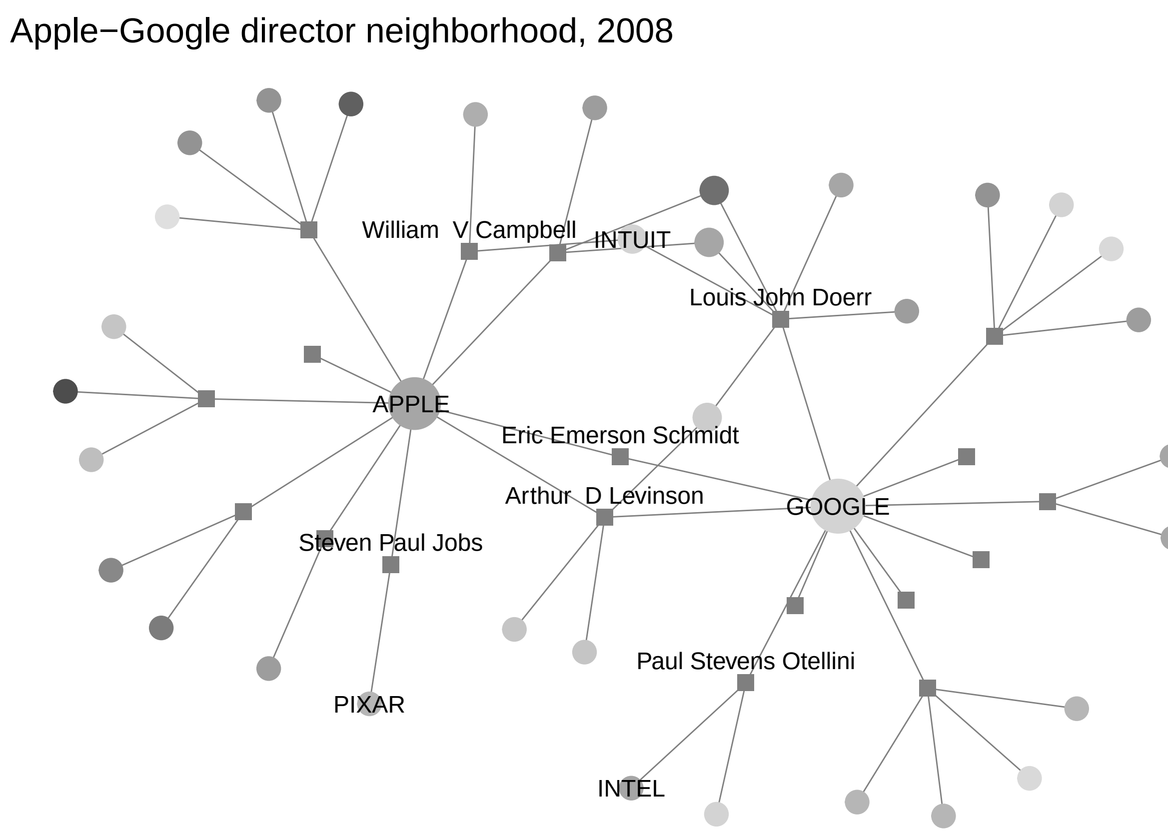

Figure 1: Director-firm bipartite network structure in the neighborhood of Apple and Google, 2008. Circle nodes denote firms, square nodes denote directors, and edges represent board appointments. Firm node color corresponds to its sector in the BoardEx data. The neighborhood is confined to a distance of two degrees: Apple and Google, their directors, and all other firms on whose boards the directors hold seats.

not immediately resolve the conflict of interests due to intricacies of modern compensation packages. In order to align incentives with the shareholders and ensure they act according to their long run interests, firms often compensate directors via stocks options or restricted stock units (RSUs), usually vesting in the years after their tenure. However, that same schedule directly exposes them to another conflict of interests with respect to rival boards on which they might serve. Suppose a director with particular industry knowledge resigns from the board of firm A, receiving RSUs that vest in 4 years, and joins the board of a rival firm B. Considering the adverse effect of B's performance on A's stock price and maximizing his individual value, that director is incentivized to pursue a less aggressive strategy for firm B, rather than the profit-maximizing one.

I use mergers and acquisitions of US companies, together with firm balance sheet data, individual-level data on board appointments and patent-level data to study the effects of interlocks on performance and innovation. I exploit events of firm mergers as exogenous shocks to director interlocks for causal identification, and find that horizontal interlocks increase firm performance, as measured by cumulative returns, by 3 percentage points. These shocks also increase the volatility of stock returns, reflecting the increased uncertainty due to the loss of information. I then provide evidence for a possible mechanism: project selection. When a horizontal interlock is severed, patenting output seems to decrease in terms of both quantity and quality in a narrow region of technology-space.

These results are consistent with horizontal directors facilitating the flow of valuable business information that reduces redundancy in two ways. First, firms can learn about the scientific progress of rival projects early on, and save costs thanks to knowledge spillovers. Leveraging successes and failures of rivals can increase R&D efficiency by either progressing faster through research phases or discontinuing failing research agenda early on. Second, the race to a patent is one of winner-takes-all, and if firms are made aware of rivals' projects, they may reallocate efforts and pursue projects with less direct competition. Similar to spatial market segmentation, keeping some technological distance helps lower competition, as well as reduce redundancy.

I contribute to the literature on corporate governance and firm performance. The common view is that boards control corporations by setting strategic goals and hiring executives, whom they subsequently advise and monitor. I provide evidence for another mechanism, where the directors are better informed about the competitive environment, and are able to control several companies. I also contribute to the broader literature on competition and collusion by suggesting a more plausible channel of a common agent. Collusion at lower levels of management seems unreasonable as a main driver due to fiduciary duties and severe sanctions, while coordination on higher levels, like the existing literature on common ownership, has been criticized for the indirect mechanism, which requires certain shareholders to affect corporate decision-making through intermediary directors. My approach "cuts the middleman" and posits a much weaker assumption of informed directors at the helm. Finally, by exploiting third-party mergers as a main source of variation in director-firm ties, I suggest a pro-competitive effect of mergers: in addition to generating market power and consummating synergies, mergers seem to disrupt communication channels of incumbent firms, which suggests that a more lenient merger policy may be optimal.

The paper is structured as follows. Section 2 reviews the related literature - mostly by economists, although sociologists and legal scholars have made important contributions to this body of knowledge. Section 3 provides some historic context on legislation and regulation from the late 19^{th} century to this day, alongside prominent examples from recent years. In Section 4 I propose a toy model of risky investment, providing a conceptual framework and intuition for the empirical findings, namely how horizontal directors can dampen competition, cut costs, and improve performance. Section 5 describes the different data sources, introduces the firm-director network graph structure, and provides summary statistics. Section 6 covers my main results on the effect of interlocks on firm performance, risk, and personnel decisions. In Section 7 I further explore a possible mechanism, using data on within-firm variation in patenting. Section 8 concludes.

2 The importance of directors

The board of directors exists primarily to solves agency problems created by the separation of residual risk from decision management, or ownership from control (Fama and Jensen 1983). A formal hierarchy of decision and monitoring is the universal approach to address the inefficiency, with the board of directors at the top of the pyramid. Tasked with selecting, monitoring, and dismissing decision agents, the board disrupts collusion between top management and control agents, allowing for the separation of ownership and control at the highest level.

In addition, directors generally fill the role of advisers, as they tend to be seasoned practitioners and executives with broad domain knowledge, connections, and experience. Unsurprisingly, firms tend to hire directors with multiple observable skills, especially in management, finance and accounting, and the particular industry. This fact provides both diversity in the available skill set, and complementarities within skills (Adams, Akyol, and Verwijmeren 2018). Industry-specific expertise is especially desirable and seems to be growing in importance, as the share of industry expert directors has been on the rise since the early 2000s, at the expense of firm insiders (Drobetz et al. 2018).

Since such observed and unobserved director abilities are generally valuable to firms, and board appointments are often not a full time job, many directors serve on multiple boards, creating interlocks. This widespread practice has been documented as early as the 19^{th} century and persists to this day (Hauser 2018), spurring debate over the importance and relevance of board structure and director busyness to firm outcomes.

Concurrent directorships, i.e. appointing a director who already holds board seats, may benefit firms by introducing better business practices, providing greater expertise, and improving prospects and opportunities through broader connections. At the same time, busy directors may exert lower effort in monitoring, or have conflicting interests with their other positions. Standard theory suggests that equating the cost and benefit of the marginal director would determine the equilibrium board composition and the entire firm-director network structure. Disentangling the two effects proves difficult, as appointments are endogenous: the busier directors may be those of higher quality and value, and therefore in high demand, making it unclear a priori which effect dominates.

Unfortunately, as is often the case within the broader corporate governance literature, there is little unifying theory related to boards of directors in general, nor interlocks in particular (Adams, Hermalin, and Weisbach 2010). While there are occasional applications of general economic theory to specific topics, such as hierarchies and supervision to questions of monitoring, free-riding to questions of collaboration, or theory of common ownership and organization to board interlocks, they only yield insights of partial equilibrium. With general equilibrium models being either too complex for estimation to be feasible or too simplistic to be credible, the vast majority of the literature is empirical.

Within this literature, the evidence on interlocks is mixed. On the one hand, there is evidence that interlocks are detrimental to firms: several studies have found that the lower effort and inherent conflict of interest outweigh the benefits of experience and connections (Loderer and Peyer 2002; Hwang and Kim 2009; Hauser 2018), and result in worse monitoring and weaker corporate governance (Yermack 1996; Core, Holthausen, and Larcker 1999; Fich and Shivdasani 2006; Masulis and Mobbs 2014). This leads to lower profitability (Fich and Shivdasani 2006) and firm value (Burak Güner, Malmendier, and Tate 2008), since directors are more likely to pursue private interests, like prestige Masulis and Mobbs (2014), and under-monitor their friends (Hwang and Kim 2009; Fracassi and Tate 2012). Reciprocal interlocks, where executives serve on each other's boards, are considered a particularly egregious practice and lead to worse performance and excessive compensation due to "back scratching" (Hallock 1997; Fich and White 2005). Exploiting second-degree connections in firm mergers, where directors from the acquirer and target firm share a third board, resolves the conflict of interest channel and suggests connections create greater value (Cai and Sevilir 2012).

Still, others conclude that interlocks are overall beneficial to firm value (Ferris, Jagannathan, and Pritchard 2003; Nguyen and Nielsen 2010; Masulis and Mobbs 2011; Field, Lowry, and Mkrtchyan 2013; Chang and Wu 2021), and that interlocks do not necessarily decrease director monitoring quality, committee service, or meeting attendance (Ferris, Jagannathan, and Pritchard 2003). Rather, director ties may improve operating performance, market-to-book ratio, and reduce earning restatements (Masulis and Mobbs 2011); reduce cash holdings, CEO compensation and earnings management, and increase dividend payouts (Zhang 2021); and destroy firm value and lower stock price when suddenly depart (Nguyen and Nielsen 2010; Masulis and Mobbs 2011). Interlocks provided by busy directors may prove especially valuable for smaller and younger firms, which require more advising than monitoring (Field, Lowry, and Mkrtchyan 2013), and when said interlocks are with financial or industry-related firms (Perry and Peyer 2005).

An important part of this literature deals with the explicit propagation of information and business practices across firms that share directors. Concurrent appointments are found to improve the success rate of mergers and acquisitions (Cai and Sevilir 2012; Renneboog and Zhao 2014), increase the quality and quantity of innovation, patenting and R&D (Chuluun, Prevost, and Upadhyay 2017; Helmers, Patnam, and Rau 2017; Chang and Wu 2021). Interlocking directors may also improve financial reporting quality (Intintoli, Kahle, and Zhao 2018), and increase similarity in terms of business practices (Bouwman 2011) and risk aversion (Gopalan, Gormley, and Kalda 2021). However, directors have also been found to diffuse adverse practices, like stock option backdating (Bizjak, Lemmon, and Whitby 2009) or earnings management (Chiu, Teoh, and Tian 2012).

Although this literature had historically focused primarily on US companies and directors, there is a growing body of work in recent years to suggest that the US is not a unique case. Interlocks have been shown to increase similarity among Chilean firms (Khanna and Thomas 2009), worsen performance of Australian pension funds (Ooi 2020), while likely not play a central role in known cartel cases across Europe (Buch-Hansen 2014). In a sample of UK firms, well-connected interlocking directors, and especially those with industry-specific expertise, appear to hold superior information and make more profitable transactions (Goergen, Renneboog, and Zhao 2019). Following a change in Italian legislation that prohibited interlocks among financial firms, interlocks have been found to increase banks' lending interest rates (Barone, Schivardi, and Sette 2022), and increase firm value by reducing information asymmetry and increase director compensation as rent sharing (Faia, Mayer, and Pezone 2021).

I stress the importance of the identity and characteristics of the interlocked firms, which received relatively little attention from scholars in the field, as a recent review of the literature points out (Schmalz 2021). Previous work that has explored interlocked firm heterogeneity finds that directors with industry-specific expertise increase firm value (Drobetz et al. 2018), and facilitate mergers by providing the acquiring firm with superior information of the target than is available to other bidders (Cai and Sevilir 2012). Considering the ownership structure of firms, Azar (2022) shows that common ownership, in addition to firm size and geographical proximity, also relates to interlocks, implying that institutional investors may influence board structure.

Finally, it is worth acknowledging that economists were not the first to study interlocks, as director networks drew the attention of sociologists and legal scholars from their inception, focusing mainly on characterizing board structures and documenting the distribution of interlocks. Sociologists have generally viewed interlocking directorates as a measure of cohesiveness of business groups (Fennema and Schijf 1978), and regarded interlocks as a system feature. Special attention was devoted to documenting the historical structure and development of director networks (Chu and Davis 2016). The US interlock network emerged as a relatively concentrated group and remained similarly dense from the early 20^{th} century until the 1980s. In the wake of growing criticism from investors, analysts and the general public following corporate scandals, the directors' public image had taken a critical hit. Contemporary rhetoric reflected the shift, gradually moving from "corporate diplomats" to "busy" and "overworked" directors (Useem 1986).

Legal scholars have also changed their understanding of boards and interlocks over time. Earlier work deemed boards in general to be mainly ceremonial and unimportant for everyday business (Mace 1971), serving more of a "boys' club". The literature has changed course since, and in recent years also paid special attention to interlocks. Interlocks are associated with higher returns and the propagation on business practices (Barzuza and Curtis 2017), more accurate reporting and fewer financial restatements (Omer, Shelley, and Tice 2020), higher rates of independent directors and the separation of CEO and chairman roles (Bouwman 2011); but also with the proliferation of option backdating (Bizjak, Lemmon, and Whitby

2009), earnings management (Chiu, Teoh, and Tian 2012), and the use of poison pills (Davis 1991). "Horizontal directors" seem to exacerbate the effects of interlocks, where within-industry information flow is more relevant and valuable, yet may facilitate collusion, block the way for diversity and new blood and increase systemic governance risk, and reduce director independence (Nili 2019).

2.1 Interlock flavors

Not all interlocks are the same: particular circumstances or the identity of the parties involved can play an important role in determining interlock value and effect on firm outcomes. In this paper I highlight a specific kind - horizontal interlocks, yet other distinctive interlock types exist and have gained the attention of scholars and practitioners, and I would be remiss not to briefly mention them. Importantly, some have been directly identified by the Federal Trade Commission (FTC) as a major antitrust concern that requires changes to existing legislation. Namely, vertical interlocks and interlocks with utility firms, together with horizontal interlocks - both direct and through a common third-party board.

Vertical interlocks. Vertical directors hold appointments in firms which are each others' immediate suppliers or client, either current or potential. The benefits accrued to a company from sharing a director with a supplier can be direct, in the form of more favorable terms, or indirect, by disrupting the supply chain of a rival firm. A common director shared with an upstream supplier may lead to preferential treatment of the interlocked firm over its competitors, resulting in increased downstream market shares, lower cost of goods, and higher markups. Indeed, there is evidence to suggest that interlocks with upstream and downstream firms are value enhancing, especially in the face of higher information asymmetry (Dass et al. 2014), and that directors in related industries are better informed of the relevant product market space, making them better monitors of firm executives and less likely to reward them for luck (Nanda and Onal 2016). Empirically, there is a particular challenge in determining supplier-customer relations, as this information is generally privileged. Instead, the recently proposed approach of Frésard, Hoberg, and Phillips (2020) assigns a probability measure at the firm pair-year level for how likely the two firms are to be vertically related, based on textual analysis of their annual reports filed with the Securities and Exchange Commission (SEC).

Financial interlocks. Sharing a director with a bank, while could be considered a special case of vertical relations, was front and center in the minds of the Clayton Act legislators. Interlocks among banks and with banks were pervasive in the early 20^{th} century US, as well as in recent developments in Europe: in 2011 Italy specifically banned interlocks in the financial sector, and nowhere else. This speaks to the fact that banks, unlike just any supplier, are deeply involved and intertwined with all sectors of the economy and may hold greater sway over the fortunes of companies. Accordingly, interlocks with banks correspond to improved outcomes: Chuluun, Prevost, and Puthenpurackal (2014) find that well-interlocked firms also have more ties to financial firms and enjoy lower financing costs, especially for opaque firms. Credit spreads decrease when new connections are established, and increase when terminated. Ties to bank and financial firms are especially beneficial to credit constrained companies.

Horizontal interlocks. Finally, when an interlock involves rival firms, some strategic aspects emerge. In settings where open communication is impossible and private information is valuable, a horizontal director may facilitate the flow of information regarding rival actions and strategy, and serve as a coordination device between competing firms. There are various other agents previously studied, through which firms may coordinate, such as executives, equity-holders, financiers, marketing agents, or regulators. Among them, horizontal directors provide an especially appealing mechanism from a theoretical perspective, as it requires fewer active agents in the process with well understood incentives.

Consider, for example, the heavily debated literature on common ownership, often in the context of large institutional investors holding shares of rival firms. Theory suggests that shareholders with stakes in rival companies have an objective function that is different from maximizing the individual firm's equity value, and would prefer a less aggressive product market strategy. Weaker pricing incentives would then lead to higher equilibrium prices, compared to a perfectly competitive market. Presumably, investors need to communicate their objective to the directors they appoint, who then need to monitor executives as they carry out a business strategy that is not optimal for the firm as a whole. This also assumes no conflict with fellow shareholders, who have no other horse in the race and would be worse off if management deviates from standalone profit maximization. For all of this to work, however, we require a good understanding of the incentives and behavior of firms, investors, boards, and executives.

In contrast, a horizontal director simultaneously serves two masters. He is directly in the driver's seat of both firms, and his wealth depends on their performance, since firms often compensate directors with both salary and equity in order to align their long-term incentive with those of the firm. Having his own total wealth in mind when considering a given firm's business plan, he is likely to weigh the appreciation in its stock value versus the decline of the rivals', and vote for less aggressive actions by both firms.

Note that the collusive setting above may not even be necessary for firms to appear as if they coordinate. A horizontal director is not merely an overt corporate spy conveying information, but a high ranking official in charge with decision-making across boards and committees. Even for the most benevolent and impartial director, it is plausible that contemporary votes with respect to similar business decisions would be correlated within a director across firms, and more so when the firms are similar or belong to the same industry. If, for example, a director deems expansion to new markets is the best course of action for a certain firm, he is likely to think the same for its comparable rival. Similarity and synchronicity in strategies among interlocked competitors may be the resulting emergent order.

I expect horizontal interlocks to have a similar effect to that of market power in increasing firm performance and value. Better information available to firms reduces business uncertainty, and a direct coordination channel can help maintain non-competitive price levels. I test this empirically by studying firm dynamics around events of interlock severance, and find that interlocks increase returns.

3 Institutional background

Interlocking directorates seem to have attracted the attention of policymakers and regulators long before that of scholars. Public concerns of monopoly power and banking concentration in the late 19^{th} century eventually led to the formation of the Pujo Committee in 1912 that would investigate Wall Street financiers. Embracing the committee's findings of pervasive collusion and market concentration among few banks, as well as a tight-knit group of interlocking directors, Democratic candidate Woodrow Wilson made antitrust a central issue of his presidential campaign. Once elected, the Wilson administration remained vocal in its criticism of interlocking directorates, relying on prominent figures such as Louis Brandeis in describing the phenomenon as inefficient, disloyal, undemocratic and "the root of many evils". Subsequently, the Clayton Act of 1914 outlawed interlocking directorates across rival firms, followed by a wave of directors resigning interlocking posts,[2] while also addressing practices of price discrimination, tying, and exclusivity. By the 1930s, however, it was apparent that the regulation has failed to achieve the desired result, as a 1935 report by the National Resources Committee found pervasive board interlocks among the largest firms: 225 of the 250 largest corporations were interlocked with others.

Little has changed over the next decades either: in a 1951 report, the FTC called for an amendment to the Clayton Act, arguing that the offense is too narrowly defined and is easily avoided in practice. Most common in the commerce and manufacturing sectors of the time, it fails to cover certain types of interlocking relations, namely interlocks with rival firms via a third-party board, public utility firms, and upstream suppliers.

Overall, there have been relatively few enforcement cases filed under Section 8 of the Clayton Act: between 1899 and 2022, the Department of Justice had only filed 11 cases under the violation of "Interlocking Directorates and Officers", out of 2368 antitrust cases in total.[3] According to the FTC, this seemingly under-enforcement is due to director resignation being the most frequent remedy, as Section 8 does not provide for civil penalties or other monetary relief and grants a one-year grace period for directors to resign.[4] This practice of securing voluntary compliance, known as "jawboning", proved effective in providing ad hoc remedies, but lacked long term deterrence. A 2009 investigation by the FTC concerning collusion in the labor market by several tech companies revealed that common directors were instrumental in coordinating hiring policies across firms. Notably, two directors, Eric Schmidt and Arthur Levinson, both held concurrent seats at the boards of Apple and Google, which they were forced to relinquish, with Eric Schmidt resigning from Apple's board of directors,[5] and Arthur Levinson resigning from that of Google.[6] However, in contrast with arguably lax enforcement

[2] Notable examples of the decline in interlocks between 1912 and 1919 are of bank horizontal interlocks (down 85%), banks-railroads interlocks (down 47%), and banks-industrials (down 32%). See Mizruchi (1982) for more detail.

[3] https://www.justice.gov/atr/antitrust-case-filings

[4] https://www.ftc.gov/enforcement/competition-matters/2017/01/have-plan-comply-bar-horizontal-interlocks

[5] https://www.ftc.gov/news-events/news/press-releases/2009/08/statement-bureau-competition-director-richard-feinstein-regarding-announcement-google-ceo-eric

[6] https://www.ftc.gov/news-events/news/press-releases/2009/10/statement-ftc-chairman-jon-leibowitz-regarding-announcement-arthur-d-levinson-has-resigned-googles

in the past, horizontal interlock cases have been more actively pursued in recent years, forcing numerous resignations where firms and directors agreed to "unwind the interlocks without admitting to liability": in 2021 the Department of Justice raised antitrust concerns regarding directorate interlocks in several sports and entertainment markets by Endeavor and Live Nation,[7] and again in 2022 with respect to five additional company-pairs across various markets, including vehicle sensors, education services, communication products, and software.[8]

4 A model of interlocks and information

In this section I propose and outline a simple model of interlocking directorates and endogenous competition intensity. The model is meant to serve as a theoretical framework for the empirical analysis, and provides intuition for a peculiar result: Horizontal interlocks increase both R&D output and distance in tech space.

The model features two firms facing a risky investment decision. Investment, in this setting, can be thought of as any expenditure with a direct adverse effect on rivals, which we would generally consider competitive: the launch of an advertisement campaign; expansion of property, plants, and equipment (PP&E) to increase production capacity; entering of a new market; or innovation and R&D efforts. Throughout the section I refer to it as R&D, as that is the context in which the model was originally conceived, but the results are very general and apply to any such investment.

In the basic setup, the model has firms only choose the intensity of investment, measured by the number of draws from a given distribution, oblivious to the actions of the rival. This serves as the baseline uncoordinated, or naive, equilibrium result. I then allow firm to hire an informed and engaged director, who gets a share of the profits and may change the distribution functions for both payoffs simultaneously. In equilibrium, the model predicts that firms with a shared director take a less aggressive stance and invest less in R&D, yet with greater success, and maintain a greater distance from each other in tech space. This section covers the model setup and equilibrium results. See Appendix C for further discussion and derivation of equilibrium conditions.

4.1 Naive game

Two identical firms, i and j, play a competitive game of R&D patenting. To participate, firms take as many costly draws as they see fit, from a known distribution, u. Let u be a uniform distribution, $u \sim U(0,1)$, illustrated by the blue line in Figure 21. If any of i's draws is far enough from and of j's draws, the firms do not directly compete and each independently succeeds in its efforts with some probability. However, if the draws are too close together, the

[7] https://www.justice.gov/opa/pr/endeavor-executives-resign-live-nation-board-directors-after-justice-department-expresses

[8] https://www.justice.gov/opa/pr/directors-resign-boards-five-companies-response-justice-department-concerns-about-potentially

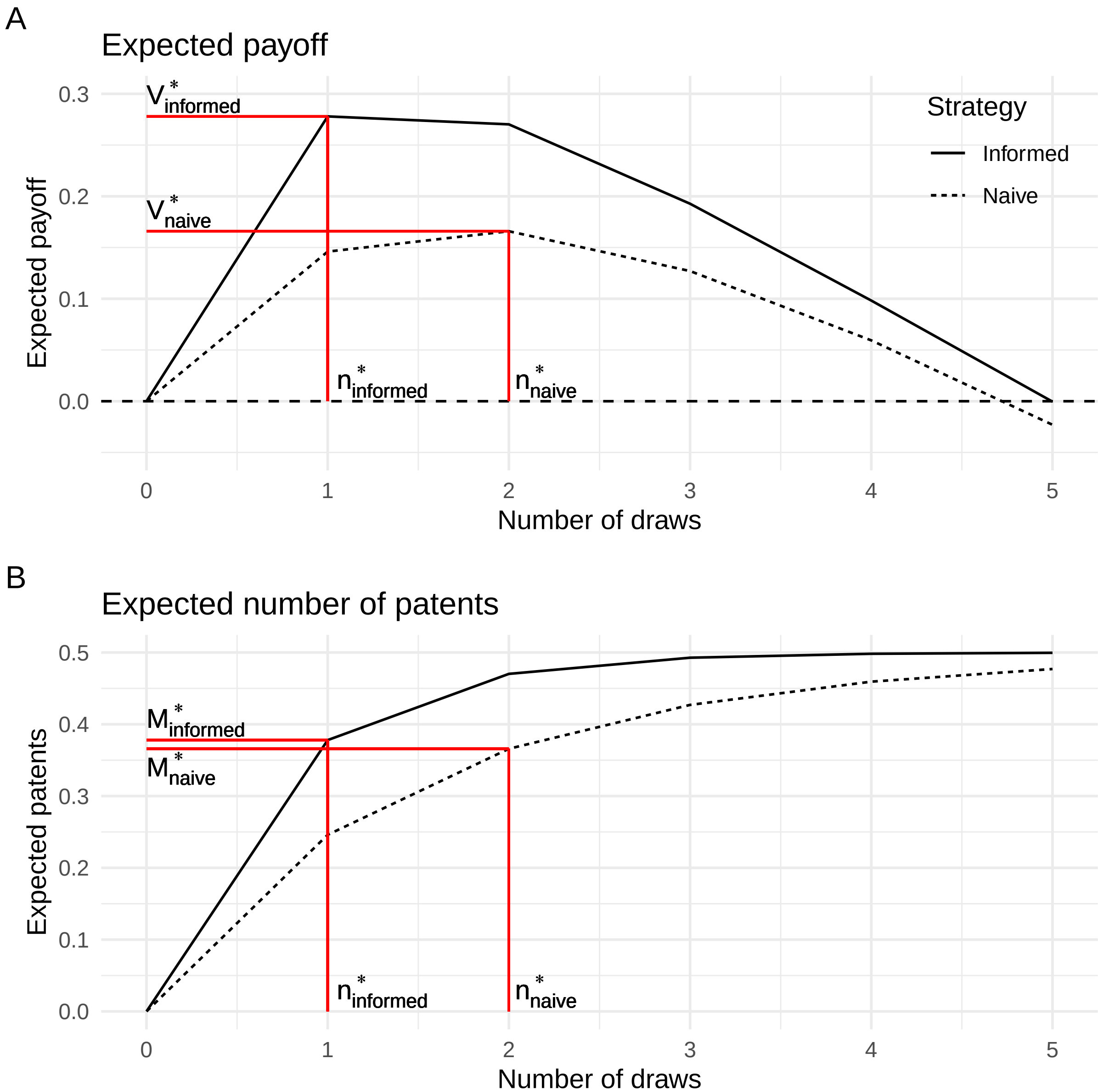

Figure 2: R&D intensity, expected payoffs and patents. Panel A plots the expected value as a function of the number of draws. Panel B plots the expected total number of patents as a function of the number of draws. The dashed line denotes the naive strategy, where firms draw from a uniform distribution, and the solid line denotes the informed strategy, where firms draw from a truncated normal distribution, with μ set by the director.

firms directly compete and at most only one may succeed, chosen randomly. This is analogous to the patent system, where the first party to file an application is granted monopoly power, while others are temporarily excluded.

Let D_{ij} be the maximal distance drawn between the two firms, and D_{min} be the minimum distance required for both firms to possibly succeed. n_i is the number of draws by firm i, and C_d is the fixed cost of each draw. $\mathbb{I}_i^{success}$ and $\mathbb{I}_i^{win}$ are indicators for whether firm i is successful in the R&D process, and whether it won the patent (if they compete). Both firms must simultaneously choose the intensity of R&D efforts, denoted by the number of draws - $\{n_i, n_j\} \in \mathbb{N}^2$.

The payoff of firm i, as a function of the number of draws and their realization, is given by Equation 1.

$$\pi_i(n_i) = \begin{cases} 0 & \text{if} \quad n_i = 0 \\ -n_i C_d + X_s \times \mathbb{I}_i^{success} & \text{if} \quad n_i > 0, D_{ij} > D_{min} \\ -n_i C_d + X_s \times \mathbb{I}_i^{success} \times \mathbb{I}_i^{win} & \text{if} \quad n_i > 0, D_{ij} < D_{min} \end{cases} \tag{1}$$

The first case is trivial, normalizing the payoff of the outside option to 0. The second case is the single-player game, where the firms land far enough from each other in tech space, and the profit comprises the payoff given success, X_s, minus the participation cost: the number of draws times the cost of each - $n_i \times C_d$. The third case is the competitive game, where the firms land too close to each other, and only one may succeed in getting the patent. The payoff is then the same as in the second case for the winner, and 0 for the loser. Note that $\mathbb{I}_i^{win}$ depends on the outcome of both firms, and equals 1 if both are successful and i wins the contest, or if only i is successful and thus wins by default.

Rewriting the payoff using indicator functions instead of case-wise yields Equation 2:

$$\pi_i(n_i) = \underbrace{-n_i C_d}_{\text{Participation cost}} + \underbrace{X_s}_{\text{Payoff}} \times \mathbb{I}[n_i > 0] \times \mathbb{I}_i^{success} \times \left(\underbrace{\mathbb{I}[D_{ij} > D_{min}]}_{\text{"Far enough"}} + \mathbb{I}_i^{win} \times \underbrace{\mathbb{I}[D_{ij} < D_{min}]}_{\text{"Too close"}} \right) \tag{2}$$

Given that the outcome is stochastic, firms maximize their expected payoff, $\mathbb{E}\left[\pi_i(n_i)\right]$. Noting that the draws are independent, the firm's problem is formalized in Equation 3:

$$\max_{n_i \in \mathbb{N}} -n_i C_d + X_s \times \mathbb{I}[n_i > 0] \times \mathbb{P}^i_{success} \times \left(\mathbb{P}_{far} + (1 - \mathbb{P}_{far}) \times \left(\mathbb{P}^j_{success} \times \mathbb{P}^i_{win} + \mathbb{P}^j_{fail} \right) \right) \tag{3}$$

Where $\partial \mathbb{P}_{far} / \partial n_i > 0$. I plot the payoff function for $X_s = 1$, $C_d = 0.1$, $D_{min} = 0.3$, $\mathbb{P}^i_{success} = \mathbb{P}^j_{success} = 0.5$, and $\mathbb{P}^i_{win} = \mathbb{P}^j_{win} = 0.5$ as the dashed line in panel A of Figure 2, denoted as the "naive" strategy. In panel B I plot the expected number of patents as a function of the number of draws for the same set of parameters. I denote by n^* the optimal number of draws, and by V^* and M^* the optimal expected payoff and number of patents, respectively.

The payoff curve trades off the certain cost of an additional draw against the increased probability of drawing a larger distance. This function is concave, as the marginal benefit of an additional draw decreases with the number of draws already taken. For the given choice of parameters, we see that the optimal number of draws is 2 per firm, yielding about 0.86 total patents (valued at 1 per patent) in expectation, and at the cost of 0.4 (4 draws in total).

4.2 Informed game

Now suppose there is an informed director whom firms may hire and can augment the distribution function of the random draws. If hired, the director takes a share of the profits and provides the firm with a new distribution function to draw from - $F_i(.)$ - a truncated normal with mean μ and variance σ^2, and the same support $[0,1]$. For simplicity, let $\sigma_i = \sigma_j = \sigma$ be given. The director chooses μ_i and μ_j to maximize his expected payoff.

The payoff of the director is given by

$$\pi_d(\mu_i, \mu_j) = \alpha \left(\pi_i(\mu_i, \mu_j) \times \mathbb{I}[\text{seat}_i] + \pi_j(\mu_i, \mu_j) \times \mathbb{I}[\text{seat}_j] \right) \tag{4}$$

Where $\alpha \in (0,1)$ is the share of the profits the director takes and π_i and π_j are the firm payoffs given the respective distribution parameters μ_i and μ_j. The setup incentivizes the director to keep the firms apart and minimize the probability of patent contest, yielding in equilibrium

$$\{\mu_i^*, \mu_j^*\} = \{0, 1\} \text{ or } \{1, 0\} \tag{5}$$

This result corresponds to the red and green lines in Figure 21, with $\sigma = 0.3$. Intuitively, the director would like to maximize the probability of success for both firms, as his incentives are aligned by construction, and the best way to do so is to have them draw from the opposite extreme ends of the distribution, where the probability of overlap is minimal. This matches the empirical evidence of horizontal interlocks increasing firm distance in tech space (see Section 7.1).

Under the new distributions, I plot the expected payoff and the number of patents as functions of the number of draws using the solid line in panels A and B of Figure 2, respectively, denoted as the "informed" strategy. The optimal number of draws is now 1 per firm, yielding about 0.88 total patents in expectation, and at the cost of 0.2 (2 draws in total). The horizontal interlock allows firms to achieve a more favorable and better coordinated equilibrium. Importantly, coordination is facilitated through an agent, without any communication or knowledge or each other's actions.

Comparing the naive and informed strategies, the model provides some theoretical predictions for the effect of horizontal directors on firm performance, R&D intensity and patent output in equilibrium. The model suggests that firms with a shared director find it optimal to reduce R&D intensity (moving from 2 draws to 1 per firm) while also increasing their value and total patent output, all due to the ability to maintain a greater distance from each other in tech space. Thus the model provides a simple explanation for several important empirical findings of this paper: Horizontal interlocks reduce uncertainty and improve firm performance (Section 6), increase distance between firms in tech space (Section 7.1), and increase total patenting output (Section 7.2).

5 The director-firm network

5.1 Data sources

I construct a novel data set, combining information from several sources, covering firm merger events, accounting data, individual board appointments, project-level R&D efforts, and patents. This section briefly reviews the various sources of data; see Appendix L for a detailed description of the entire sample construction process.

Data on corporate boards and committee structure come from BoardEx, which also collects information on firm and director characteristics, compensation packages, and director network of connections. BoardEx gathers data on about 1.5 million board members and senior executives across 2 million public firms, private firms, and not-for-profit organizations worldwide. Consistent data coverage effectively starts in 1999, although sparsely available for earlier years as well.

Firm accounting data come from Compustat. The data set encompasses income statements and balance sheet items, such as assets and sales, for all public US firms. Other variables, including markup and returns, are derived from these fundamentals. I use pairwise measures of firm similarity and relatedness, developed in Hoberg and Phillips (2016) and Frésard, Hoberg, and Phillips (2020), which are also derived from Compustat data. The two metrics rely on textual analysis of firm business descriptions and represent the probability of any two firms to be rivals in the product market or vertically related.

Information on mergers and acquisitions comes from Refinitiv SDC Platinum data set, which covers 1.3 million deals from 1979 and onward, and contains details on the characteristics of each transaction and all parties involved. Individual patent data come from the United States Patent and Trademark Office (USPTO). I match patents to firms using linking tables from Kogan et al. (2017), which cover more than 3 million patents from 1920 to 2020, and include forward citations and value of innovation.

5.2 Summary statistics

Table 1 presents summary statistics for the Compustat-SDC-BoardEx merged data set as a whole, and Table 2 splits the sample by treatment assignment. A representative board consists of about nine members, many of whom hold concurrent appointments, creating five

Table 1: Summary statistics of firm characteristics in the merged Compustat-SDC-BoardEx data set. All variables are at the firm-year level. Total assets is the Compustat item 'at' for book assets; RND is the ratio of total research and development expenses (Compustat item 'xrd') to total assets. ROA is return on assets, the ratio of operating income before depreciation ('oibdp') to total assets. Market-to-book ratio is total assets ('at') plus the market equity ('csho' × 'prcc'), minus common equity ('ceq'), divided by total assets ('at'). Markup is total sales ('sale') divided by cost of goods ('cogs') minus 1. Stock return volatility is the annualized standard deviation of daily stock returns.

	Obs	Mean	Std. dev.	Median	5%	95%
Total assets (Bn USD)	48728	8.37	59.50	0.82	0.03	26.88
Total sales (Bn USD)	48728	4.17	17.45	0.59	0.02	15.38
R&D (share of assets)	23769	0.04	0.06	0.02	0.00	0.17
Leverage	48575	0.24	0.22	0.21	0.00	0.64
ROA	48728	0.10	0.10	0.10	-0.05	0.25
Market-to-book ratio	48728	1.61	0.80	1.35	0.84	3.35
Markup	48728	0.65	0.48	0.51	0.11	1.67
Stock return volatility	48084	0.48	0.31	0.41	0.18	1.02
Directors	48728	9.07	2.83	9.00	5.00	14.00
Interlocks	48728	4.88	4.82	4.00	0.00	14.00
Horizontal interlocks	48728	0.65	1.32	0.00	0.00	3.00
Any merger-shock	48728	0.77	0.42	1.00	0.00	1.00
Horizontal merger-shock	37429	0.18	0.39	0.00	0.00	1.00

interlocks on average. Horizontal interlocks are a relatively rare occurrence, averaging fewer than one per firm. About 3 in 4 firms in my sample are merger-shocked at some point, and of those, roughly 1 in 5 involved an acquisition within the sector. Comparing across the treatment and control groups, the firms are generally comparable and vary mostly in mean size, whether measured by assets or sales, with the untreated being more than twice as large. These differences are mostly driven by the right tail of the distribution, and the median size for the untreated is only larger by less than 20%. Summary statistics of director characteristics are in Appendix I.5.

5.3 Board interlocks

Firms are interlocked if they share a common director. Appointment-level data from BoardEx specify the exact date when a director joins or leaves any particular board committee (like audit or compensation) and his role on each (like chair or member). I abstract away from individual committees, and construct a dummy variable at the director-firm-year level to indicate whether the director held a seat on that firm's board at any time during the year. Next, for every firm and year, I count the number of other board seats each director holds per sector to obtain the number of interlocks he creates - overall and within the sector.

Table 2: Means and standard deviations of firm characteristics by merger shock type. The sample is split according to treatment assignment: omitted (no shock), control (non-horizontal interlock) and treatment (horizontal interlock) groups. All variables are at the firm-year level. Total assets is the Compustat item 'at' for book assets; RND is the ratio of total research and development expenses (Compustat item 'xrd') to total assets. ROA is return on assets, the ratio of operating income before depreciation ('oibdp') to total assets. Market-to-book ratio is total assets ('at') plus the market equity ('csho' $\times$ 'prcc'), minus common equity ('ceq'), divided by total assets ('at'). Markup is total sales ('sale') divided by cost of goods ('cogs') minus 1. Stock return volatility is the annualized standard deviation of daily stock returns.

	Horizontal interlock		Non-hor. interlock		No merger shock	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Total assets (Bn USD)	4.69	18.24	11.77	74.22	1.40	8.44
Total sales (Bn USD)	2.16	4.81	5.93	21.68	0.60	1.81
R&D (share of assets)	0.06	0.08	0.04	0.06	0.04	0.06
Leverage	0.23	0.22	0.26	0.22	0.22	0.22
ROA	0.09	0.10	0.11	0.09	0.07	0.10
Market-to-book ratio	1.64	0.81	1.67	0.80	1.43	0.74
Markup	0.73	0.50	0.61	0.45	0.71	0.51
Stock return volatility	0.47	0.28	0.46	0.29	0.55	0.35
Directors	9.20	2.92	9.47	2.74	7.90	2.68
Interlocks	4.78	4.34	6.14	4.95	1.52	2.61
Horizontal interlocks	1.39	1.90	0.63	1.22	0.26	0.90
Firms	744		2512		1509	
Observations	6854		30575		11299	

I document a stylized fact - firms with more interlocks perform better. I estimate this relation in Equation 6, and plot the coefficients in Figure 3.

$$\text{ROA}_{jt} = \sum_{k=1}^{10} \beta_k \mathbb{I}[\text{Interlocks decile}_{jt} = k] + \varepsilon_{jt} \tag{6}$$

The dependent variable ROA_{jt} is firm j's return on assets in year t, defined as the ratio of operating income to total assets, and interlocks decile is a vector of ten dummy variables corresponding to equally-spaced breaks in the distribution of interlocks. Better firms tend to be larger, and therefore have larger boards, so I scale the number of interlocks by board size to assure the correlation is not there by construction. The relation is almost entirely monotone and nearly linear; The slope of the trend-line is about 0.5pp. However, since board appointments and firm performance are jointly determined, many factors may drive the result, and not necessarily that interlocks increase returns. For example, well-governed firms are more likely both to outperform poorly-governed rivals and to hire more independent directors, who tend to hold concurrent seats. For a causal interpretation we need shocks to board seats that are exogenous to unobservable determinants of firm performance.

Cross-firm interactions through interlocks require us to consider the non-linear, network structure of the data, best described as a *graph*. A graph comprises a set of *nodes*, which are connected by *edges*. A *bipartite graph* is a special case where nodes have two types, and edges may only connect nodes of different types. In our case, firms and directors are the two sets of nodes, and board appointments are the edges. To study the network, and particularly how tight-knit different parts of it are, we first need to establish a way to represent and summarize its structure. A common way to describe graphs is using an *adjacency matrix*, A, where element $A_{ij} = 1$ if nodes i and j are connected, and 0 otherwise. Indexing directors and firm by $i = 1, \ldots, N$ and $j = 1, \ldots, J$, A_{ij} equals 1 if i holds a seat on the board of j.

A graph's *density* is the share of possible links that are present: of all $N \times J$ directors and firms in existence, what share actually matched. Formally, define a graph's density as:

$$\text{Density}(g) = \frac{1}{N \times J} \sum_{i,j} A_{ij}$$

Figure 4 plots annual graph densities over the entire sample and within-sector averages, and the ratio of the two. First, we see that the global density is significantly lower than within sector; averages about 0.02% and remains approximately constant over the 20-year period. To illustrate, this is equivalent to having a single firm-pair interlocked in a set of 100 firms. Within a sector, the graph is both denser and increases in density over time. Trending roughly in parallel with the global density for the first half of the sample, relative sector density increases in the second half. Overall, the graph is more concentrated within sector than across, and concentration increases over time: sector density had risen from about 0.08% to 0.14% over 20 years, or from a single interlock in 50 firms to one in 37, all in the same sector.

Next, I introduce several standard measures of network centrality: *betweenness*, *closeness*, and average *degree*. A node's degree is the total sum of its edges: for a firm, that measures

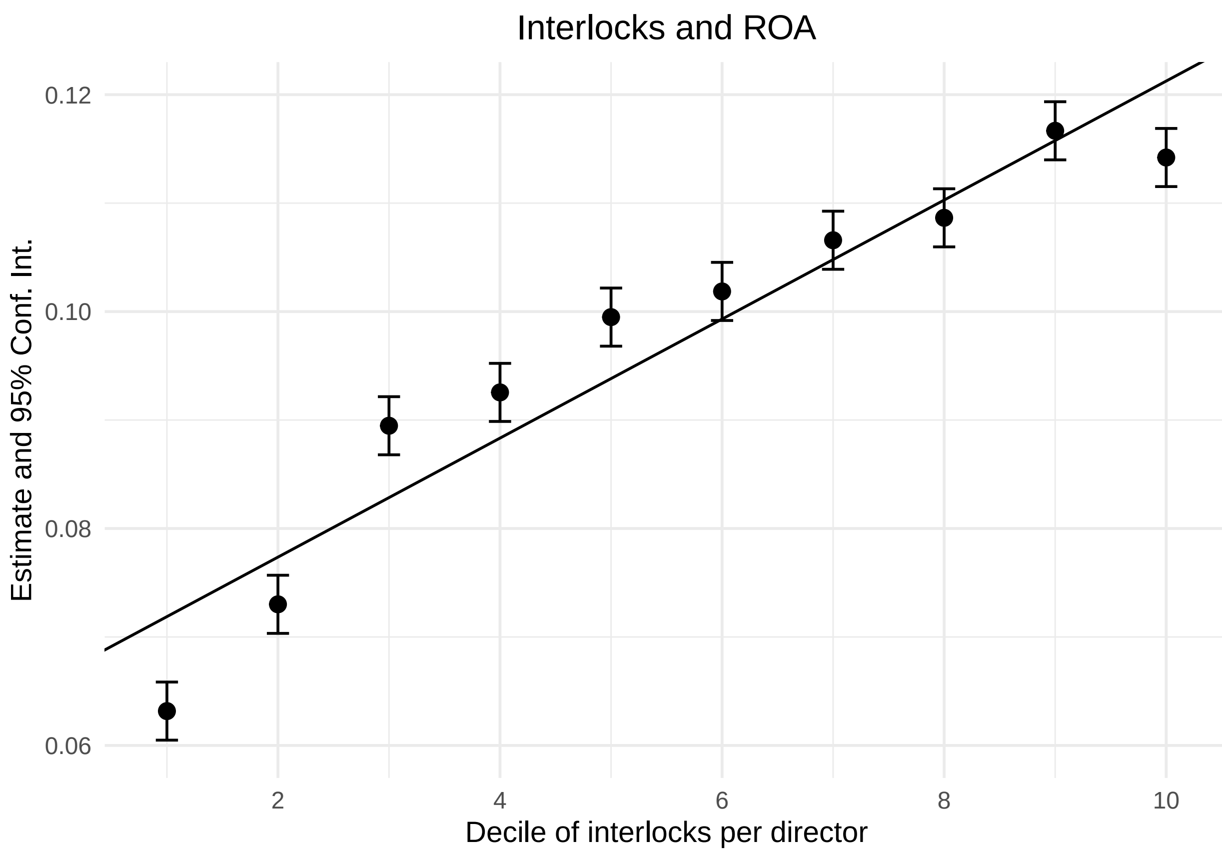

Figure 3: Return on assets by interlock deciles. The figure plots the β_k estimates from a linear regression, at the firm-year level, of annual returns on the number of interlocks, scaled by board size and binned by deciles:
$\text{ROA}_{jt} = \sum_{k=1}^{10} \beta_k \mathbb{I}[\text{Interlocks decile}_{jt} = k] + \varepsilon_{jt}$.
On the vertical axis are the regression coefficients and standard errors, and on the horizontal axis are deciles of the total number of interlocks divided by board size. Annual returns are defined as the ratio of operating income before depreciation (Compustat item 'oibdp') to total assets (Compustat item 'at'). Board size is the number of unique directors holding an appointment at the end of the calendar year. The number of interlocks is defined as the sum of all board seats held by all board members on other distinct boards.

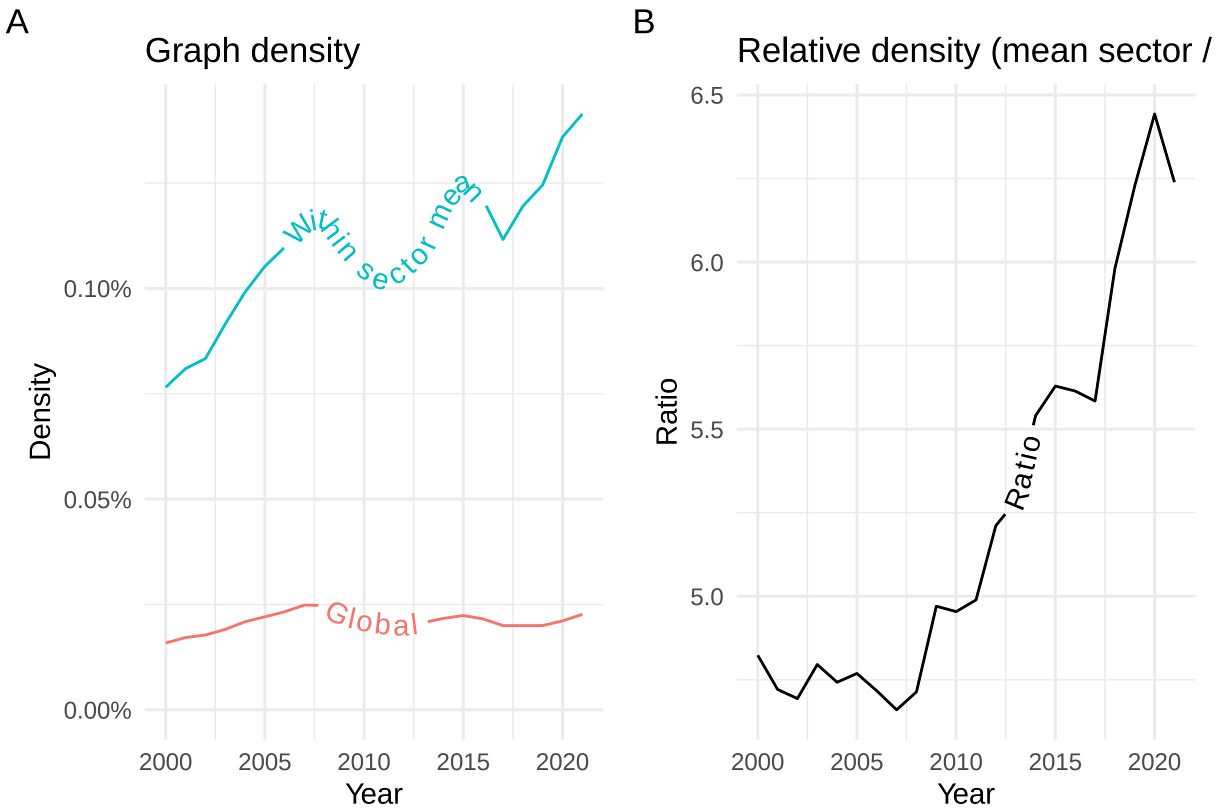

Figure 4: Firm graph density dynamics. A graph's density is the share of possible edges present: the ratio of observed to potential interlocks by year. Nodes represent firms, and edges represent directors. I plot the number of observed interlocks divided by the number of total possible interlocks in any given year. The global density is calculated over the entire sample, and sector mean is the average density across sectors. On the right axis, the dashed line corresponds to the annual ratio of the sector-average to the global density.

its board size; for a director - the number of concurrent seats.[9] Betweenness captures the number of shortest paths in a graph that pass through a given node; The intuition is that a high betweenness centrality node is more important and has more control over the network. Closeness centrality measures the inverse of the sum of all shortest path between a node and all other nodes.

To show that the relative increase in sector concentration is not driven by the metric of choice, Figure 5 plots the evolution of the three centrality measures, both for the global network and average across sectors. All values are normalized to 0 in the year 2000. Over the last 20 years, the average out-degree increased both globally and within a sector, indicating that the average director interlocks more non-rival and rival firms than in the past. Closeness centrality has been declining, which is expected as a network grows in terms of node count. The decline is less steep when evaluated within industry, suggesting network growth is not uniform across sectors. Node betweenness has been initially increasing globally and within sector, but plateaued globally around 2005 while continued to rise locally, implying growing sectorial "inner circles" of very well connected nodes.

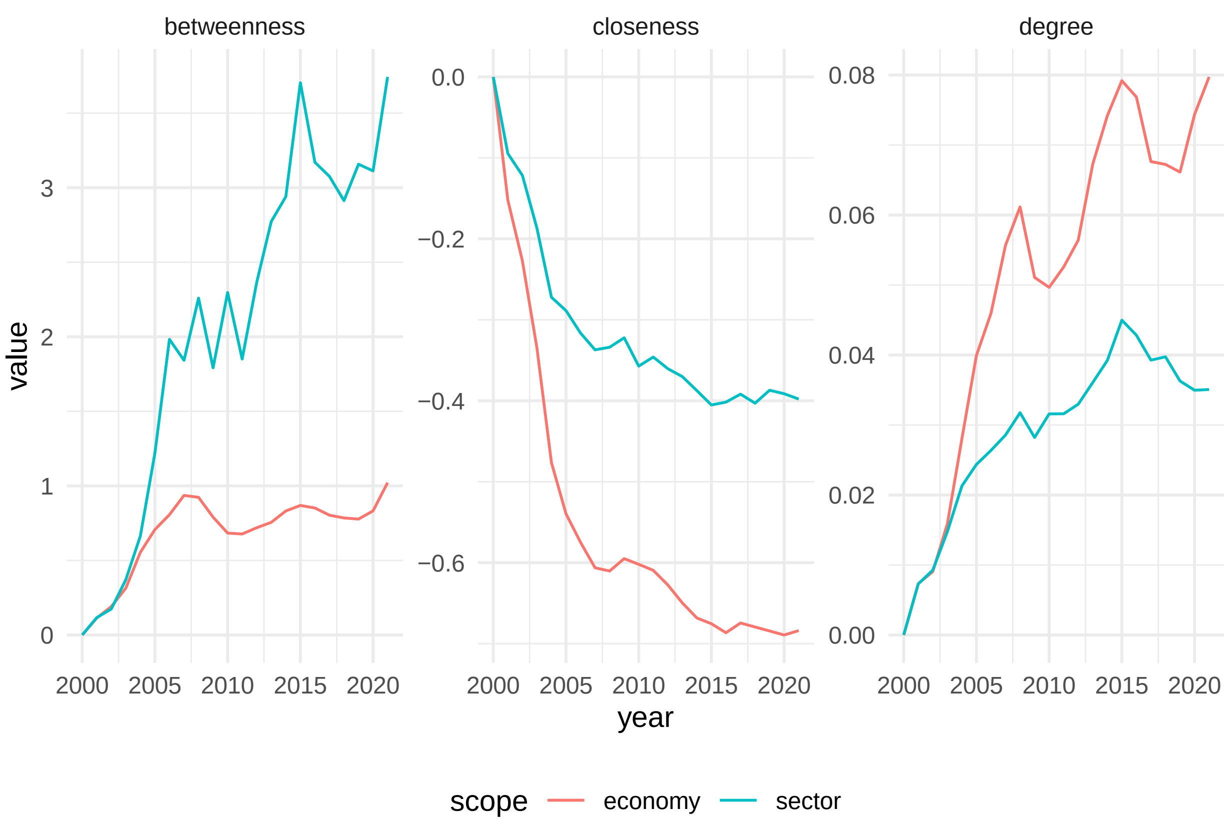

Figure 5: Director network relative centrality, global and sector-average, 2000-2021. Betweenness, closeness and mean degree centrality measures are normalized to 0 in the year 2000.

[9]A *directed graph* offers a similar distinction. Suppose edges are directed from directors to firms. *In-degrees* count the number of edge "heads" pointing to a node, and would equal the board size for firms and 0 for directors. *Out-degrees* count edge "tails", and return the number of seats for directors and 0 for firms.

Going beyond the observed average trends, Figure 6 plots the distributions of the three centrality measures, on a log scale, as they evolve over time. Notably, betweenness had grown a fat right tail over the years: in relatively few sectors emerged very central nodes, while the entire density mass did not shift much. The opposite is true for closeness and degrees. Closeness very visibly shifted left, in addition to a growing left tail; while the average degree distribution moved to the right, with a similar right tail. Very low values of closeness in 2020 suggest that the network becomes wider over time, and higher degree values are a direct indication of horizontal interlocks.

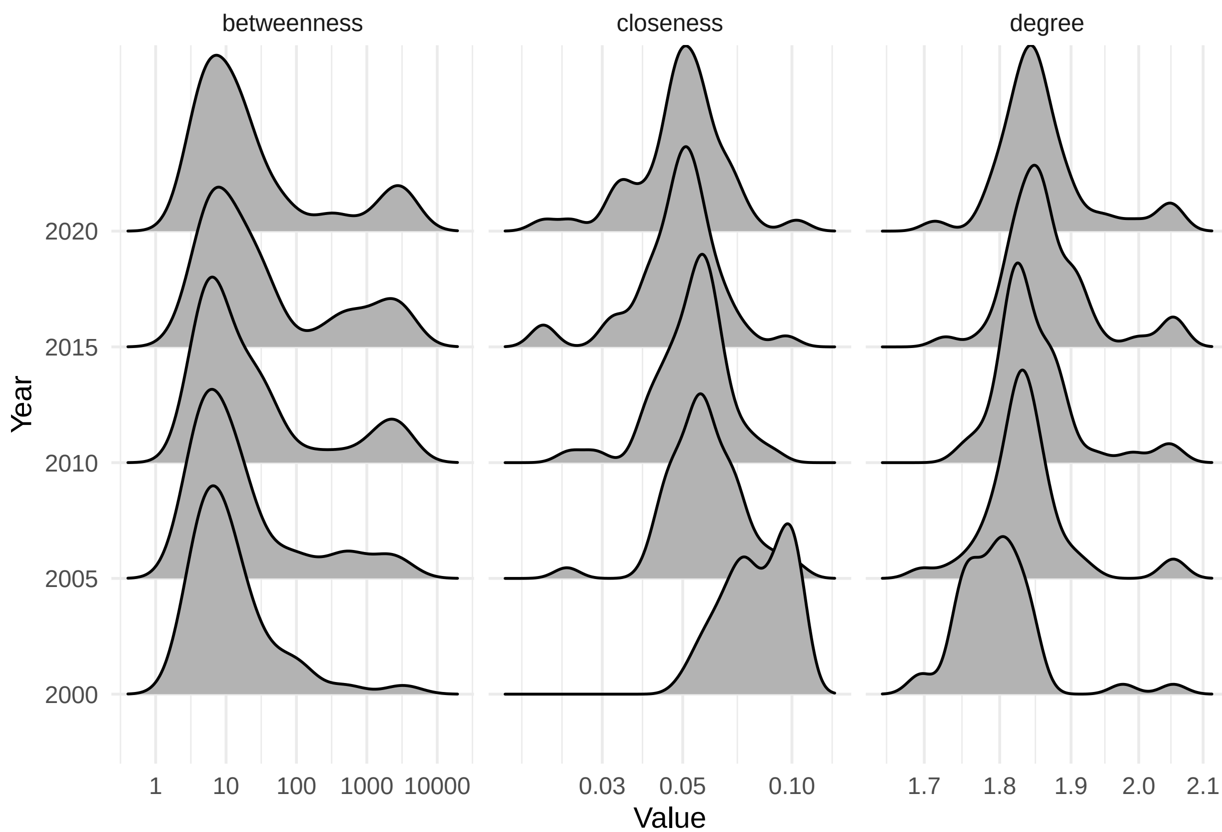

Figure 6: Director network sector-level centrality distribution, 2000-2020. Annual densities for betweenness, closeness and mean degree centrality measures are presented in 5-year increments from 2000 to 2020. The horizontal scale is log-transformed.

The Pharmaceuticals and Biotechnology sector is a prime example of noticeable changes to the local network. To illustrate, I take two points in time - the years 2000 and 2020, and count the number of different board seats each director holds within the sector. I plot the seat distribution histogram in Figure 7. Directors serving on exactly one board in the industry do not create interlocks among rivals; directors with two or more seats are horizontal directors. From 2000 to 2020, the entire distribution shifted to the right: the share of non-horizontal directors dropped from 73% to 58%. Having a director with more than 3 concurrent appointments withing the sector had been an extreme rarity in 2000, at under 2% or directors, and has grown to to roughly 10% of all pharmaceutical directors in

2020.

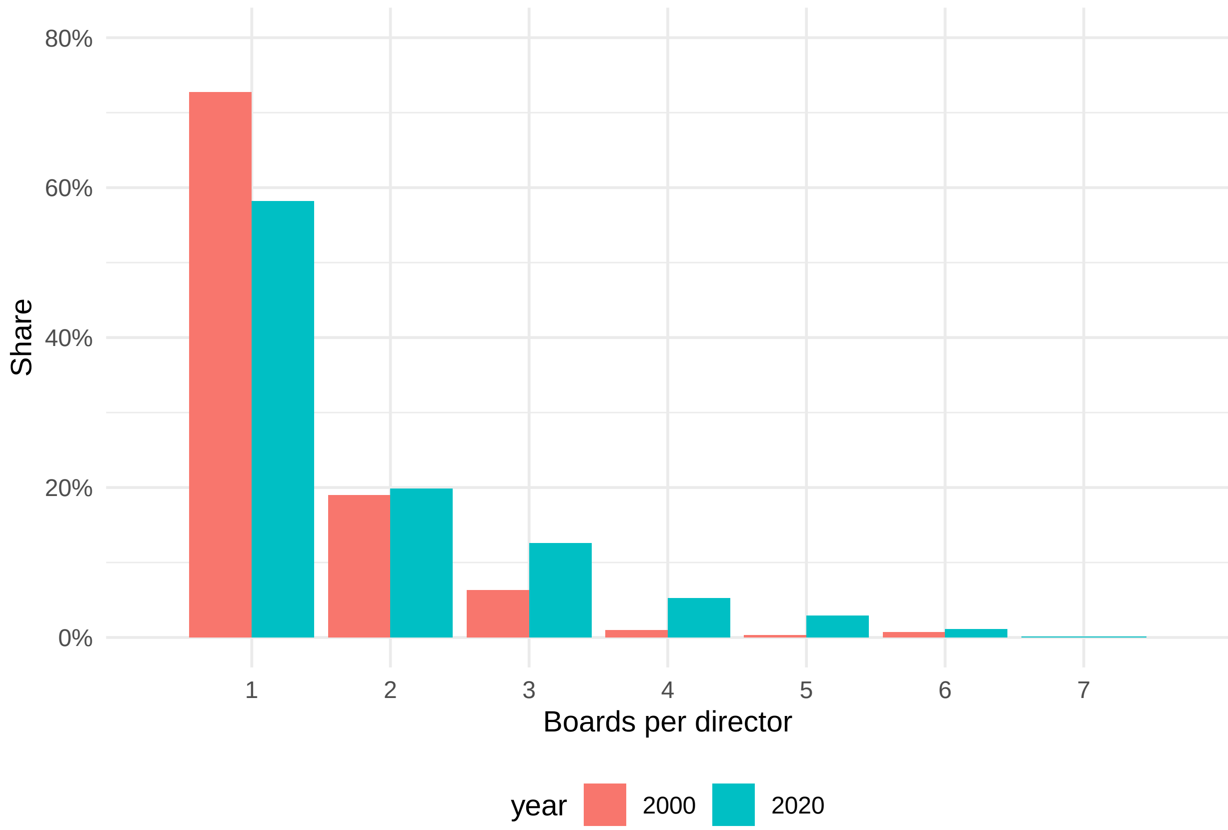

Figure 7: Distribution of board per director in US Pharmaceuticals and Biotechnology sector, 2000 and 2020. The figure plots a histogram of the number of concurrent seats directors hold within the sector.

5.4 Merger shocks

For identification of the causal effect of interlocks, I use mergers and acquisitions (M&A) as exogenous shocks to the network. To illustrate, consider the following example. In 2008 Hewlett-Packard Co (HP) acquired Electronic Data Systems Corp (EDS) for nearly 14 billion USD. On the eve of the merger, EDS had 12 board members, holding seats at 21 other firms among them, illustrated in Figure 8. After completing the deal, and as part of EDS's integration as a business unit of HP, its entire board was dissolved. From the point of view of the firms interlocked with EDS, regardless of sector affiliation, their directors exogenously lost a seat and decreased total workload: one M&A deal, 21 merger-shocked firms. However, sectors are important: certain firms were operating in unrelated industries, such as Pepsico, and may generally benefit from the increased attention of the less-burdened director; others, like Eclipsys and Intuit, may be positioned much closer in both technology and product space, and thus suffer the loss of a valuable information channel.

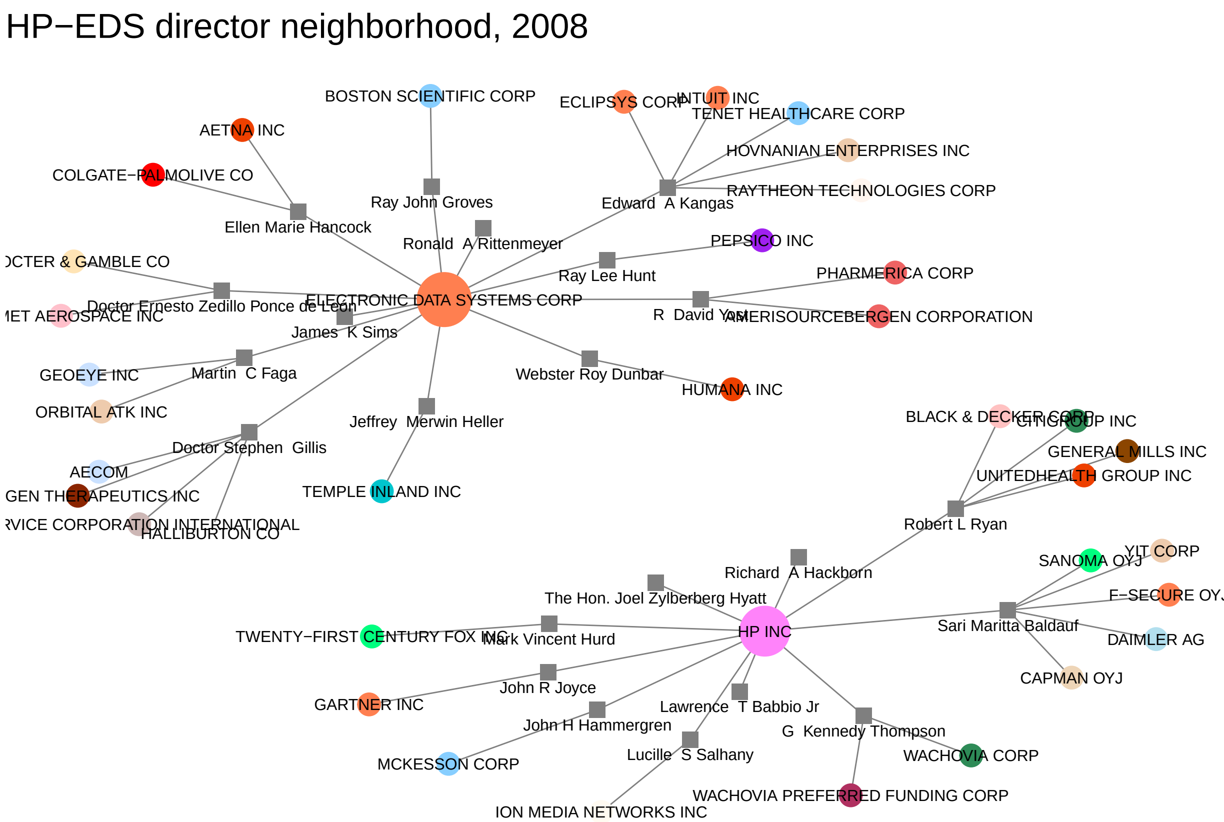

Figure 8: Director-firm bipartite network structure in the neighborhood of Hewlett-Packard and Electronic Data Systems, 2008. HP acquired EDS at the end of the year. Circle nodes denote firms, square nodes denote directors, and edges represent board appointments. Firm node color corresponds to its sector in the BoardEx data. The neighborhood is confined to a distance of two degrees: HP and EDS, their directors, and all other firms on whose boards the directors hold seats.

Using third-party mergers provides an opportune setting to disentangle the two effects: directors' effort and information. Under the identifying assumption that unrelated mergers are as good as random, so is the sector to which the target firm happens to belong to.

One concern may be that firms are not acquired at random and directors are not terminated arbitrarily: Target firms may be prone to takeovers because of poor management, and once acquired, the new owners may selectively retain the best directors and dismiss the rest. I address the endogeneity in two ways and use a relatively narrow definition for merger-shocked firms. First, the target firm must be acquired entirely, and not just a partial stake in it. This is observable in merger filings and explicitly reported in SDC Platinum data. Second, I only ever consider the outcomes of firms interlocked with targets, never the target firms, and impose the exclusion restriction that acquisition timing is exogenous to the *interlocked* firm's unobservables. Third, I omit cases where the target kept operating as a stand-alone enterprise and retained some or all of its board. In my sample the target's whole board is terminated.

6 The ambiguous effect of interlocks on performance

6.1 Research design

In an ideal experimental setting, directors would be assigned to boards at random, in a manner completely unrelated neither to their skills and preferences, nor to the characteristics and requirements of companies. We could then observe performance around the time when directors join or leave, randomly creating or severing interlocks across a panel of firms, and credibly infer a causal effect, captured by β in the linear model of Equation 7, where j and t index firms and years.

$$\text{Performance}_{jt} = \beta \text{Interlocks}_{jt} + \varepsilon_{jt} \tag{7}$$

Unfortunately, that is not our world. Estimating the above equation, using annual return on assets as a measure of performance, implies $\beta = 0.3$pp, but we have little reason to interpret the relation as causal. Firm performance and board seats are jointly determined, as directors and firms match and separate on both observable and unobservable confounding characteristics, violating the necessary random assignment above. By merely documenting business growth as a director joins the board, we cannot identify the causal effect of the director and interlock on performance, nor even determine its sign. Consider a firm that appoints a new "busy" director to the board, thus creating a new interlock, and its profits increase. In this setting we cannot discriminate between a company that pursues lucrative and complex projects and hires an expert director for better advising and monitoring, and one that happens to hire a director whose connections and expertise then facilitate business growth.

The endogeneity concern only grows once we consider the bipartite graph structure of the director-firm network, and the fact that firm outcomes, covariates, and directorships themselves are all determined jointly. Endogenizing the network structure, together with node and edge features is well beyond the scope of this paper, but a very important avenue to explore. Instead, I abstract away from the sparse network structure, and consider a variation of the linear-in-means approach of Manski (1993). As a source of exogenous variation in the network structure, I use firm mergers that result in board dissolution. An alternative approach, using director deaths, is discussed in Appendix G, and yields similar results.

6.2 Merger shocks

For identification, I require exogenous variation in director appointments to serve as a quasi-experiment. To that end, I use merger-induced board shocks as a natural experiment: incidents when a director loses a position on an acquired firm's board, causing all other firms he directs to exogenously lose the interlock. The identifying assumption is that the acquisition is orthogonal to unobservable characteristics of the other interlocked firms. An important advantage of this approach, compared to studying firms when directors join *their* board, is that it allows me to tease apart the network structure from director unobserved ability. In this setting, firms only ever lose the interlock and never the director himself. On the other hand, the severance of interlocks may have effects of different magnitude or trajectory than those of interlock creation. It is easy to imagine how business relations and directors' familiarity with projects take time to develop, while severance is instantaneous. Indeed, I only use data on interlock unwinding, not forging, for causal inference, and in my discussion of the results I explicitly assume the effects to be interchangeable. The main reason for not using appointment events is an omitted variable bias - unobservables such as director ability that determine both hiring decisions and firm performance. I am not aware of convincingly plausible exogenous variation *at the appointment phase* that would allow a causal interpretation.

One endogeneity concern might be that treatment assignment is not quasi-random: acquiring firms would, on occasion, retain directors of target firms to continue their oversight of the merged business activity. If better directors are retained while worse ones are let go, individual ability is again a confounding factor, invalidating the exclusion restriction. I address this by restricting my attention to mergers where the entire board was dismissed, which is likely a top-down decision unrelated to individual director abilities. Another concern may be that mergers affect interlocked firms through channels other than their shared director, like changes to aggregate supply due to market power, or renegotiating vertical contracts thanks to increased bargaining power. These mechanisms vary in theory according to the relation of interlocked firms. For firms in distant and unrelated sectors, I argue the exclusion restriction credibly holds. For firms with some horizontal or vertical relations, on the other hand, that may not be the case. However, as long as these effects are assumed to be industry-wide, similarly impacting all firms in a given sector, like the exit of a rival uniformly reducing competition, I account for them by conditioning on unobservable industry-year fixed effects.

The next natural step would be to define the treatment group as firms with a director that has lost a seat at another board after an acquisition, and the control group as firms with no change in interlocks. However, never-treated firms have no concept of relative-time and although alternative approaches exist, like assigning it to the last pre-period, they do not accommodate standard difference-in-differences diagnostics such as testing for pre-trends. Instead, I focus the main analysis on the ever-treated subset of firms and assign firms according to the nature of the severed interlock: I define the treatment group as firms for whom a merger severed an interlock with a firm *in the same sector*, and the control group as firms for whom a merger severed an interlock with a firm *in a different sector*.

I estimate a staggered dynamic difference-in-differences model, formalized in Equation 8:

$$\text{Cum. ROA}_{jt} = \sum_{k=-5}^{5} \alpha_k \mathbb{I}[\tau_{jt} = k] + \sum_{k=-5}^{5} \beta_k \mathbb{I}[\tau_{jt} = k] \times \text{Treat}_j + X_{jt}\gamma + \delta_j + \xi_{st} + \varepsilon_{jt} \tag{8}$$

Let firms and years be indexed by j and t. I discretize the state-space and consider the board state at the firm-year level, although in practice firms may appoint or dismiss directors at any moment. ROA_{jt} is the cumulative return on assets of firm j by year t. Let $\tilde{t}_j$ is the first year in the sample when firm j is merger-shocked, i.e. a director on its board had lost a concurrent appointment at another firm k due to an acquisition. Using that year as reference, I define relative time, $\tau_{jt} = t - \tilde{t}_j$, and restrict my attention to a fixed window around the merger event: $\tau_{jt} \in \{-5, \ldots, 5\}$. Treat_j equals 1 if the shock to firm j is horizontal, or within-sector,[10] and X_{jt} is a vector of firm characteristics, like size, leverage, R&D expenditure, and volatility. δ_j and ξ_{st} are firm and sector-year fixed effects, and ε_{jt} is an *iid* error term.

I use a dynamic difference-in-differences framework with staggered treatment timing, and only consider the first merger-shock per firm. This allows me to circumvent concerns regarding repeated treatment or arbitrary cutoff points for when one shock's post period becomes the pre-period of the next shock. In Section 7 I use a similar framework to explore within-firm and across-technology variation in patent production around merger-shocks, where I redefine markets in terms of technology, rather than sector.

6.3 Disentagling effort and information

I begin with exploiting my main source of quasi-random variation in board interlocks: third-party mergers. I define mergers-induced director shocks, following Hauser (2018), as interlock severance due to a third-party merger. To illustrate, suppose director i serves on the boards of firms A and B, when B is wholly acquired by firm C and its board is let go.[11] Firm A is merger-shocked when director i loses his seat on the board of firm B following the acquisition. Firm A is further horizontally merger-shocked - or treated - when it is both merger-shocked and shares the same industry with firm B.

[10] I define industries according to the BoardEx 'Sector' variable, which follows the FTSE Industry Classification Benchmark (ICB), as this offers the maximum data coverage. See Appendix E for a discussion of market definitions and a set of robustness tests using GIS, NAICS, and SIC classifications instead.

[11] I intentionally restrict my analysis to the subset of mergers that result in complete ownership and entire board dissolution. Avoiding cases where some board members are retained by the acquiring firm addresses endogeneity concerns of the acquirer selecting which directors to keep on their unobservables. While the acquiring firm's governance structure decisions are clearly not random, they are more likely to be unrelated to unobserved director characteristics.

A causal interpretation relies on the assumption that the treatment assignment is orthogonal to firm unobservables. In other words, the exclusion restriction requires firm acquisitions to be independent of the prospects of other firms with which the target shares a director, other than through that director's appointment. To violate the identifying assumption, there needs to be some omitted variable that affects returns and systematically coincides with merger timing.

This approach deviates from the prevailing use of variation in within-board composition, which reflects personnel changes ranging from plausibly exogenous (director death) to clearly endogenous (appointment, resignation). Even in the more credible scenario of interlocking directors suddenly passing away and replaced by non-interlocking directors, it is difficult to disentangle the confounding effects of lost connections and director ability. Using merger-shocks offers the clear advantage of teasing apart the network effect from that of the director. Within this framework, merger-shocked firms only ever lose the interlock, but never the director himself.

Figure 9 plots the dynamic effect of losing a horizontal interlocks on cumulative returns - vector β_k from Equation 8. Controlling for unobserved firm and sector-year fixed effects, firms who lost a horizontal interlock under-perform by about 3pp, compared to firms losing a non-horizontal interlock. This effect manifests immediately and persists for the remainder of the period, meaning that firms do not seem to compensate for the losses over the following years. See Appendix I for a set of robustness tests, including pre-trends, static difference-in-differences specifications, the use of director deaths as the exogenous shock to the network, different industry specifications, and a comparison between the interaction-weighted estimator for dynamic treatment effects of Sun and Abraham (2021) and a naive two-way fixed effects (TWFE) model.

Overall, I estimate the effect of horizontal interlocks on ROA to be on the order of 3pp across different specifications. Extrapolating using the average treated firm size, a simple back-of-the-envelope calculation suggests that the indirect losses incurred by mergers are on the order of 141 million USD per firm, or 105 billion USD over the entire sample period.

6.4 Potential channel and heterogeneity

I estimate a general effect of interlocks on firm performance. Next, I explore some important heterogeneity in the effect across features of the shocked firm, its competitive setting, and its relation to the merger target.

First, there is evidence to suggest that interlocks lower information asymmetry. Figure 10 plots the effect of horizontal interlocks on annualized daily stock return volatility for each relative year around merger shocks. I find no change for non-horizontal interlock severance, and a sharp 4 point (8%) increase in volatility for firms losing a horizontal interlock, which attenuates over time. This is very much in line with the anecdotal evidence from the 2010 High-Tech no-poaching DoJ case mentioned above, and is consistent with horizontal directors holding private information that lowers uncertainty and cash flow volatility among competitors. When a connection is lost, perceived business risk immediately increases.

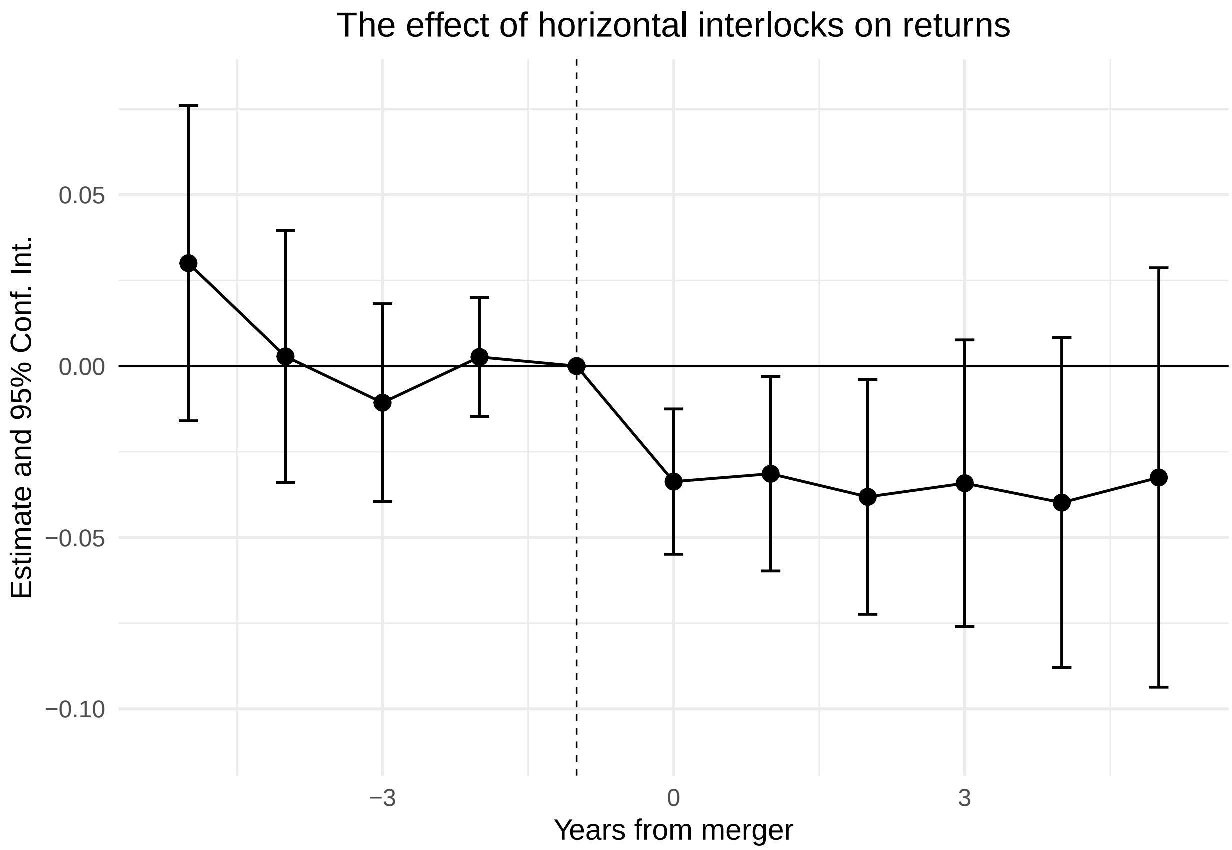

Figure 9: The effect of horizontal interlocks on cumulative ROA. The figure plots regression coefficients from Equation 8, corrected for dynamic heterogeneity in the treatment effects. Observations are at the firm-year level. The estimation includes firm and sector-year fixed effects. Standard errors are clustered by firm and sector-year.

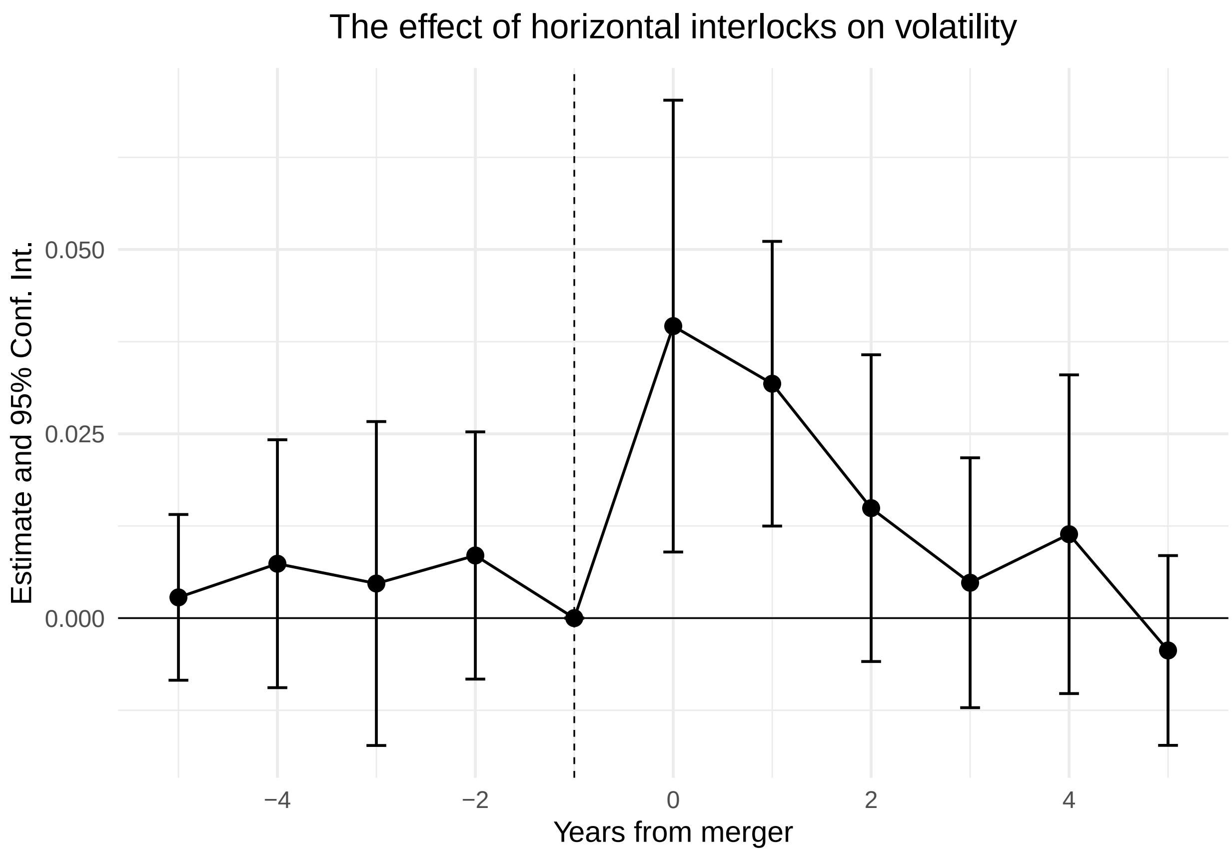

Figure 10: The effect of horizontal interlocks on stock return volatility. Observations are at the firm-year level. Volatility is the annualized standard deviation of daily stock returns. The estimation includes fixed effects at the firm and sector-year levels, and corrected for dynamic heterogeneous treatment effects using the interaction-weighted estimator of Sun and Abraham (2021). Standard errors are clustered by firm and sector-year.

Next, I explore the heterogeneity in the effect of horizontal interlocks across firm and market characteristics: size, risk, and competition. Hypothetically, horizontal interlocks may be more impactful for riskier firms, where private information is more valuable. Similarly, interlocks may be more valuable in markets with medium levels of concentration: When concentration is high, and the number of competing firms is low, companies could more easily have other ways to coordinate; and in very diffused markets, we would expect competition to drive profits down, leaving little to gain from the director's informational edge, together with tacit collusion being more difficult to sustain.

I proxy size using total sales, risk using leverage, and competitiveness at the sector level using the Herfindahl-Hirschman index (HHI) of market concentration. For size and risk, I compute deciles with respect to the year and sector level, and for HHI - with respect to the year. I estimate Equation 9, which is the static counterpart of Equation 8, interacted with deciles of firm size, risk, and competition:

$$\begin{aligned} \text{Cum. ROA}_{jt} = & \sum_{d=1}^{10} \alpha_d \mathbb{I}[D^X_{j,-1} = d] \times \text{Post}_{jt} \\ & + \sum_{d=1}^{10} \beta_d \mathbb{I}[D^X_{j,-1} = d] \times \text{Post}_{jt} \times \text{Treat}_j \\ & + X_{jt}\gamma + \delta_j + \xi_{st} + \varepsilon_{jt} \end{aligned} \tag{9}$$

Where $D^X_{j,-1}$ is the decile of firm j's characteristic X in the year before the merger shock, and Post_{jt} is a dummy variable that equals 1 in the year of the merger shock and onwards.

In the three panels of Figure 11 I plot the vector of coefficients of the interaction term, β_d, corresponding to X being size, leverage, and HHI. Despite the flexibility of the model specification, the estimates are close to linear: the effect of horizontal interlock severance on performance decreases in leverage, increases in HHI and does not correlate much with size. I find that horizontal directors are more valuable for riskier firms. Firms with higher leverage are inherently more susceptible to business uncertainty and variance in cash flows, which private information can help reduce. Consistent with the previous literature, I also find that horizontal directors are more valuable when collusion is otherwise difficult, like in low-concentration markets. In highly concentrated markets tacit collusion is possible to sustain through channels other than directors, such as regulators or suppliers, so the loss of the interlock is not as impactful when a common director is not the only channel of communication. When market concentration is low, on the other hand, horizontal directors provide a rare and valuable information channel, and performance suffers significantly when that connection is lost.

Horizontal interlocks are also more valuable the closer the two firms are in product space. Figure 12 plots the interaction terms of Post $\times$ Treat from Equation 9 with tertiles of the cosine similarity measure of Hoberg and Phillips (2016). The metric captures how close any two firms are based on textual analysis of their business description in the annual 10-K forms filed with the SEC, and maps it to the $[0, 1]$ interval. I use tertiles instead of the more flexible deciles due to data constraints - a large portion of firm-pair similarities are 0. Still, I find a greater drop in performance when similarity is higher, suggesting that interlocks are more valuable for closer rivals.

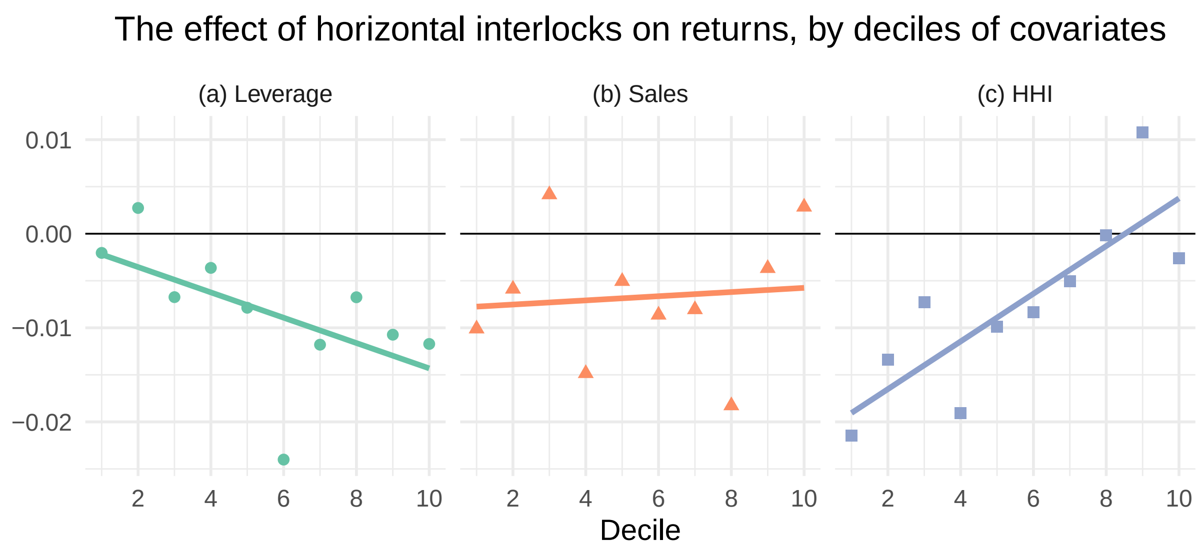

Figure 11: Heterogeneity in the effect of horizontal interlocks on returns. The figure plots the interaction coefficients of the post-period dummy, the treatment group dummy, and deciles of leverage, sales, and HHI. Observations are at the firm-year level. The estimation includes fixed effects at the firm and sector-year levels. Standard errors are clustered by firm and sector-year.

6.5 Changes in personnel and re-interlocking

The previous section presents estimates of a significant positive effects of horizontal interlocks on returns. If that is true, we should expect to see firms respond and adjust their conduct to compensate for the lost connection. Indeed, there is evidence indicating that firms react to severed interlocks by selectively expanding their boards and creating new interlocks.

I estimate the effect of merger-shocks on board size using the same framework as before, but with the dependent variable being the number of directors on the board, rather than returns, and plot the coefficients for the dynamic horizontal effect in Figure 13. Losing a horizontal interlock causes firms to increase the board by 0.4 directors, on average. I interpret this pattern as firms actively seeking to forge new interlocks. The effect attenuates over the years, but remains significant into year 4. Importantly, the firms in my sample do

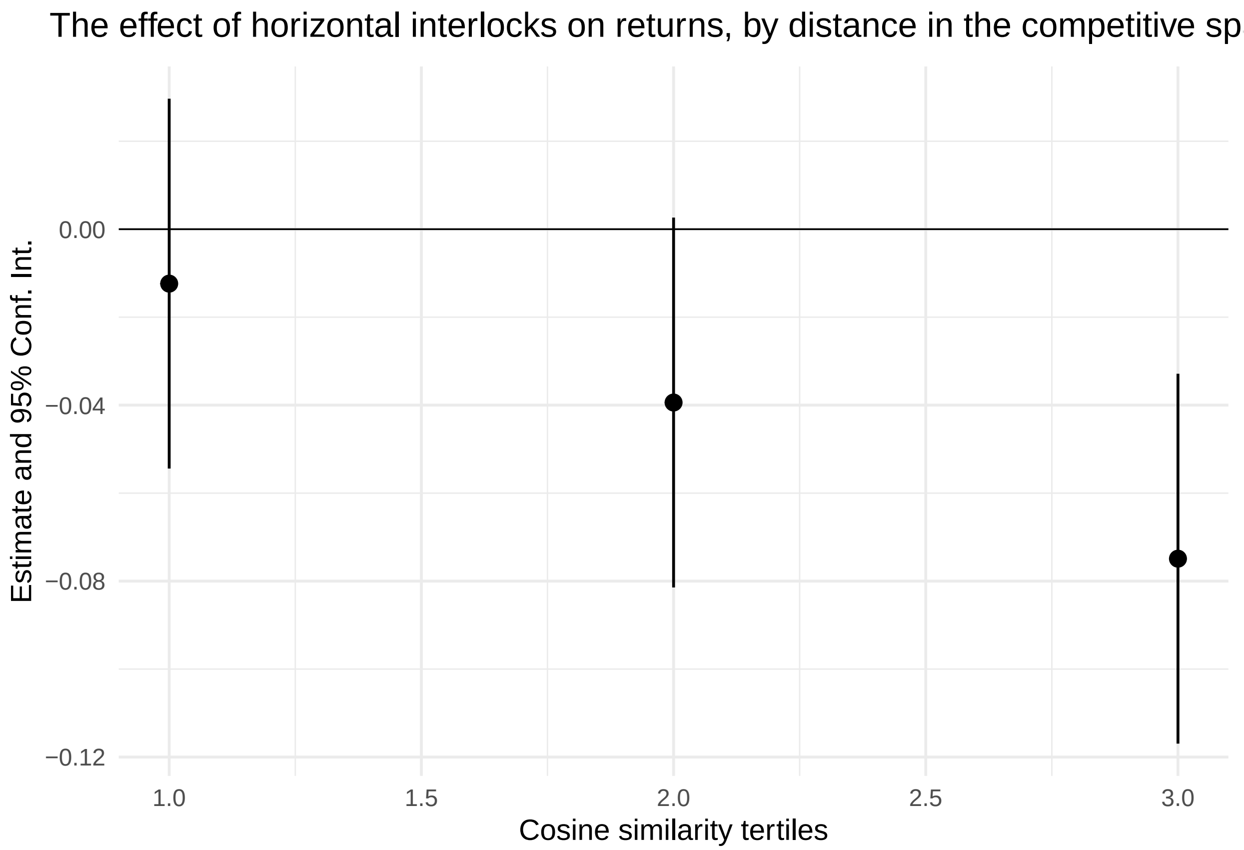

Figure 12: Heterogeneity in the effect of horizontal interlocks on returns, by tertiles of cosine similarity. The figure plots the interaction coefficients of the treatment effect and tertiles of pairwise cosine similarity (Hoberg and Phillips 2016) between the target merger and target shocked firm. Standard errors are clustered by firm and sector-year.

not systematically lose board members around the merger events, and the new appointments are not replacing sudden vacancies, which would be the case when interlocks are lost due to deaths of directors.

Figure 13: The effect of horizontal interlocks on the number of unique board members. The figure plots coefficients from regressing board size on relative time, treatment, and their interactions. The estimation includes fixed effects at the firm and sector-year levels, and corrected for dynamic heterogeneous treatment effects using the interaction-weighted estimator of Sun and Abraham (2021). Standard errors are clustered by firm and sector-year.

The newly hired directors are also likely to already have existing appointments within the sector and create new horizontal interlocks. I estimate the effect of merger-shocks on the probability of hiring a new director, creating a new interlock, and creating a new horizontal interlock, using a probit model with the same specification as Equation 8, and plot the marginal treatment effects in Figure 14. As a baseline, in any given firm and year, the probabilities of hiring a new director, creating a new interlock, and creating a new horizontal interlock are roughly 17%, 4%, and 0.5%, respectively. Immediately after the shock, firms in the treatment group are 12pp (70%) more likely to hire new directors, 8pp (200%) more likely to create new interlocks, and nearly 1.5pp (300%) more likely to create new horizontal interlocks. The probabilities spike for one year and drop back down in the following period. This is possibly because having already reoptimized in the first year, firms are less likely to change again. The findings also suggest that firms likely do not face substantial challanges in achieving their desires board composition, as the one-step deviation imposed by the merger shock is mostly answered in a single step in the following year.

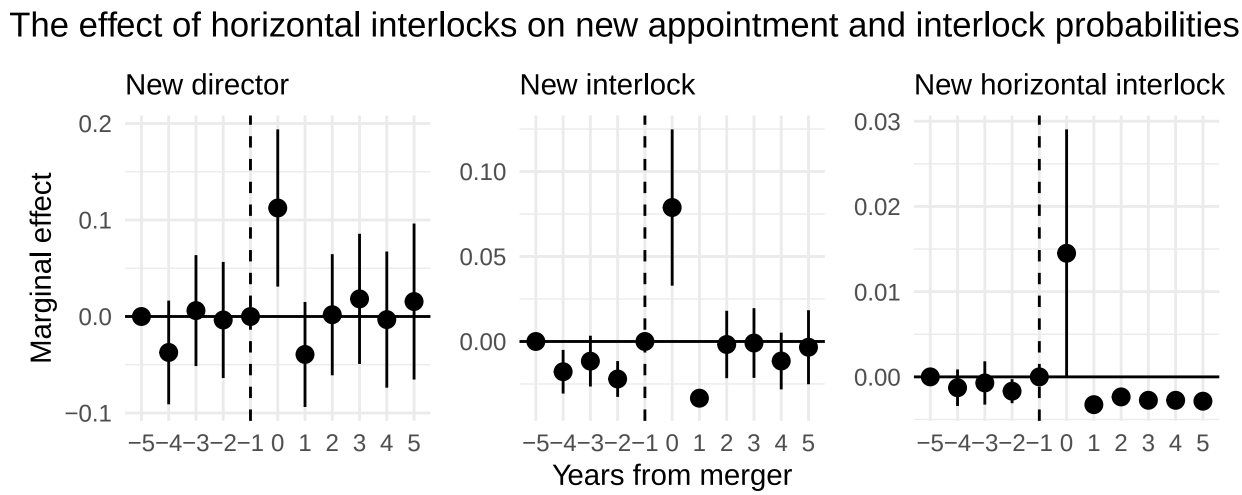

Figure 14: Mean marginal effects of horizontal interlocks on the probability of new directors and interlocks. I estimate a probit model where the dependent variable is an indicator for appointing a new director, creating a new interlock, and creating a new horizontal interlock, regressed on relative time, treatment, and their interactions. The figure plots the marginal effects of treatment by relative year on the probability of hiring a new director, creating a new interlock, and creating a new horizontal interlock. The estimation includes fixed effects at the firm and sector-year levels. Standard errors are clustered by firm and sector-year.

Do these actions translate into performance? I re-estimate the effect of horizontal interlocks on returns, interacted with an indicator for appointing a new director after the merger shock, and plot the coefficients in Figure 15. Indeed, firms that hire new directors after the shock experience a smaller drop in returns, compared to firms that do not, suggesting that firms are able to compensate for the lost connection by appointing new directors. Still, I would be cautious in interpreting this as a causal effect, since firms that hire new directors are likely to be different from those that do not. It should also matter when that new director is appointed: if the new director is appointed immediately after the shock, the firm would have had less time to suffer from the lost connection, compared to a firm that hires a new director in later years. Similarly, I do not condition on whether the new director created interlocks in general, nor horizontal ones in particular. The data are too sparse for the above interactions to have statistical power, and I leave this for future work.

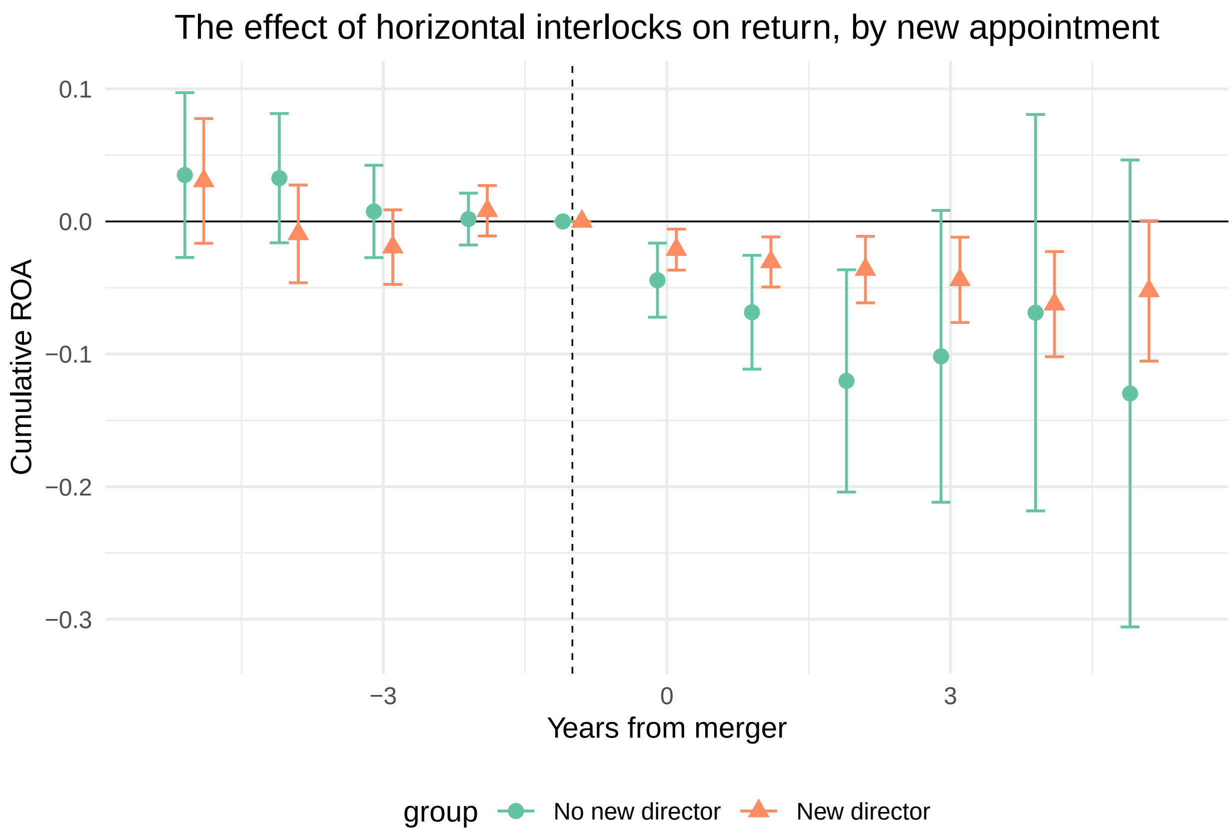

Figure 15: The effect of horizontal interlocks on returns, by new appointments. The figure plots the β_k coefficients from Equation 8, split by whether the shocked firm appointed new directors after the shock. The estimation includes fixed effects at the firm and sector-year levels, and corrected for dynamic heterogeneous treatment effects using the interaction-weighted estimator of Sun and Abraham (2021). Standard errors are clustered by firm and sector-year.

Another testable hypothesis is that after merger-shocks, the shocked firm should be more likely to terminate the (no longer) horizontal director. If firms value horizontal directors due to the interlocks they create, then the severance of such connections due to merger-shocks decreases director value. I test this using the board appointment panel data for the subset of merger-shocked firms: I estimate the effect of losing a seat on the board of the shocked firm on the probability of termination. Within a given shocked firm, I compare the employment dynamics of the shocking director (i.e the one losing another seat to a merger) and all other directors. Formally, I estimate Equation 10:

$$\text{Termination}_{ijt} = \sum_{k=-5}^{5} \alpha_k \mathbb{I}[\tau_{jt} = k] + \sum_{k=-5}^{5} \beta_k \mathbb{I}[\tau_{jt} = k] \times \text{Treat}_{ij} + \delta_{jt} + \xi_{it} + \varepsilon_{ijt} \tag{10}$$

Where Termination_{ijt} equals 1 if director i holds a seat on the board of firm j in year $t-1$ and no longer does so in year t. Treat_{ij} equals 1 if director i is the one “shocking” firm j

by losing a seat at a rival firm, severing the horozontal interlock. ξ_{it} are director-year fixed effects, and δ_{jt} are firm-year fixed effects which can now absorb previously used covariates, such as size, leverage, volatility, and R&D expenditure. I plot the β_k coefficients in Figure 16.

The estimated effect is negative in the pre-period, while the director maintains the interlock, and positive in the post-period, when the interlock is severed. A horizontal director is 2pp less likely to leave a firm (from a baseline of about 5%), compared to his peers on the board. Once the interlock is lost and the director is no longer horizontal, he is 3pp more likely to leave. The difference is statistically significant and quite substantial, nearly tripling the probability of termination. This suggests that firms value horizontal directors for the interlocks they create, and when those connections are severed, the director becomes less valuable to the firm. It is unlikely to be driven by the shareholders letting directors go after inferring that they are of low unobserved ability, since I restrict the analysis only to instances where the entire board is dismissed, rather than having directors selectively retained.

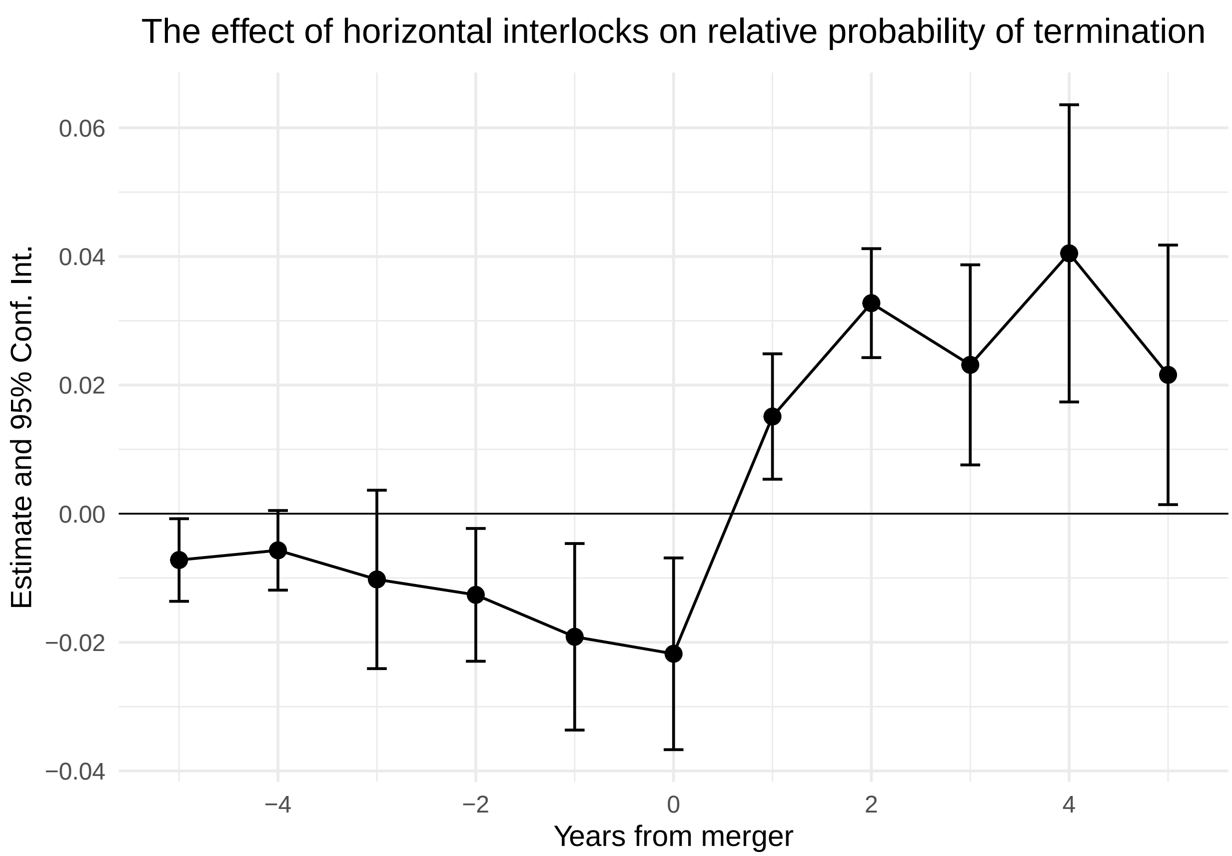

Figure 16: The effect of horizontal interlocks on own board appointment. The figure plots coefficients from regressing an inticator for director-firm severance on relative time, an inticator for the horizontal directors, and their interactions. The estimation includes fixed effects at the firm-year and director-year levels, and corrected for dynamic heterogeneous treatment effects using the interaction-weighted estimator of Sun and Abraham (2021). Standard errors are clustered by firm-year.

7 Interlocks in technology space

The results and discussion so far are mostly driven by firm-level data, where I provide evidence in support of a causal effect of horizontal interlocks on returns. These data, however, do not tell much of the transmission mechanism mapping director connections to firm outcomes, nor of internal changes occurring within the firm. In this section I propose a possible transmission mechanism of knowledge spillovers and market segmentation, and provide more granular empirical evidence to support it.

My premise is that directors observe scientific progress within the firm and possess private information on project quality. The intuition is that a common director, while not necessarily a scientist or expert in a narrow field of research, is still aware of the type of research being done and of project successes and failures in the firms he directs. Acting on private information, he may help reallocate rivals' R&D efforts toward more successful projects at the expense of failing ones. This could be as banal as exchanging contact details between scientific teams and units with potential for synergies, and as substantial as pivoting whole departments away from niches where a rival is about to achieve a major breakthrough and dominate the market.

Sharing information across firms regarding successful and failed experiments, for example, may reduce R&D costs and spur innovation: a firm can leverage others' breakthroughs to jump ahead in the research process, or nip failing research agenda in the bud. Similarly, directors can help firms reduce competition in technology space and focus their R&D efforts in fields that are close enough to benefit from knowledge spillovers, yet not too close to directly compete. Segmenting the competitive space is especially valuable in settings of winner-takes-all, such as patenting, where monopoly or property rights are awarded for an extended period of time. An interlocking director reduces uncertainty and R&D costs, and increasing innovation when such communication is otherwise impossible.

I use individual patent-level data from USPTO and compute annual firm aggregates at the section, class, and subclass levels of the cooperative patent classification (CPC) scheme.[12] The CPC patent hierarchy consists of 9 sections, ~450 classes, and ~150,000 subclasses. To illustrate the hierarchy's granularity, section G corresponds to physics in general, class G21 to nuclear physics, and subclass G21C to nuclear reactors. Subclasses are then further divided into groups, main groups, and eventually over 250,000 subgroups, at the highest level of resolution. I summarize patents at the firm-year-subclass level, and compute aggregate innovation value and forward citations following Kogan et al. (2017), and inflated to 2023 terms using the consumer price index (CPI).

Table 3 characterizes the patenting structure of firms in my sample. The average firm produces 48 patents per year, spread across 7.5 different subclasses and 4.5 classes, spanning 2 sections. Table 4 summarizes the average aggregate patent output at different levels within the firm. As a whole, the average firm produces 48 patents per year, as mentioned above, valued at over 600 million USD, and bearing over 600 forward citations. Focusing on my unit of observation, the average firm produces 6.5 patents per subclass per year, which are valued at 82 million USD and cited 83 times.

[12] https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html

Table 3: Summary statistics of patenting classification at the firm-year level. The table reports the mean, standard deviation, and quartiles of the number of distinct patents that a firm in the sample produces per year, and how the patents are distributed across sections, classes, and subclasses. Firms with 0 patents throughout the sample are omitted.

	Obs	Mean	Std. dev.	p25	p50	p75
Sections	42281	2.13	1.58	1	2	3
Classes	42281	4.50	7.93	1	2	4
Subclasses	42281	7.45	17.89	1	2	6
Patents	42281	48.35	238.02	1	4	15

Table 4: Patent output by CPC granularity. The table reports the mean, standard deviation, and quartiles of the number of distinct patents, their innovation value, and forward citations, aggregated at different levels of patent classification. Firms with 0 patents throughout the sample are omitted.

	Obs	Mean	Std. dev.	p25	p50	p75
Firm-year						
Count	42281	48.35	238.02	1.00	4.00	15.00
Value	42281	607.80	3394.39	2.14	12.37	99.39
Cites	42281	615.76	3449.70	7.00	40.00	196.00
Firm-year-section						
Count	90148	22.68	108.94	1.00	3.00	9.00
Value	90148	285.07	1687.79	2.39	11.72	70.08
Cites	90148	288.80	1693.89	3.00	21.00	105.00
Firm-year-class						
Count	190225	10.75	57.75	1.00	2.00	5.00
Value	190225	135.09	984.83	2.24	9.82	42.40
Cites	190225	136.86	970.84	2.00	12.00	54.00
Firm-year-subclass						
Count	314786	6.49	36.45	1.00	1.00	4.00
Value	314786	81.64	620.31	1.93	8.34	31.90
Cites	314786	82.71	635.56	1.00	9.00	38.00

7.1 Technology space proximity

I study within-firm dynamics using patent-level data and show that horizontal directors reduce competition and help firms avoid direct contest by maintaining distance in technology space. First, I follow Bloom, Schankerman, and Van Reenen (2013) and compute pairwise firm patent correlations, as a proxy for technological similarity. For every firm-year I aggregate all patents at the class level, summarize over a 5-year rolling window, and compute the share of every class in the firm's patent portfolio. For every firm-pair and year, I correlate the two class-share vectors yielding a *pairwise similarity index*, denoted by ρ_{ijt}, across the entire technological frontier. If interlocking directors help firms keep their distance in patent space, we should expect an increase in similarity only when a *horizontal* interlock is severed. Non-rival firms may continue to collaborate and communicate through other means, while rivals cannot.

I estimate Equation 11, which carries the same structure as Equation 8 on the right-hand side. ρ_{jt} is the similarity index of firms j and i, where firm i is acquired and j is merger-shocked. I omit the i subscript since it does not vary within j, as I only consider the first merger-shock.

$$\rho_{jt} = \sum_{k=-5}^{5} \alpha_k \mathbb{I}[\tau_{jt} = k] + \sum_{k=-5}^{5} \beta_k \mathbb{I}[\tau_{jt} = k] \times \text{Treat}_j + X_{jt}\gamma + \delta_j + \xi_{st} + \varepsilon_{jt} \tag{11}$$

Figure 17 plots the β_k coefficients from Equation 11, capturing the dynamic treatment effect. I find an increase in similarity for the treated group in the post period, meaning that rival firms move closer together in the competitive space and are more likely to patent in similar classes after losing the interlock. This result suggests that in the presence of a horizontal director, firms are better able to stay out of each other's way in segmenting the technology space. After losing the interlock, competitive pressure seems to steer them towards closer contest. Since the specification controls for sector-year fixed effects, we can rule out both a general convergence of the industry as a whole towards specific fields of research and merger-induced changes in market competition as potential alternative explanations.

7.2 Within-firm patenting

In this section I estimate the effect of horizontal interlocks on patenting output at the subclass level and study spillovers within classes and sections. The motivation for exploring this level of granularity is that an interlock is a valuable information channel under two conditions: the information is relevant, as with neighbors in technology space; and the two firms cannot otherwise communicate, as in the case of rivals. I capture the two dimensions using variation in the patenting history of the merger target, which allows me to identify scientific peers; and the merger-shock treatment, as defined in Section 6.

Every firm holds a certain patenting profile of particular subclasses where it has accumulated knowledge and expertise. For a given firm pair, some subclasses will overlap across the two more than others, and in those cases we should expect an interlock to be more valuable,

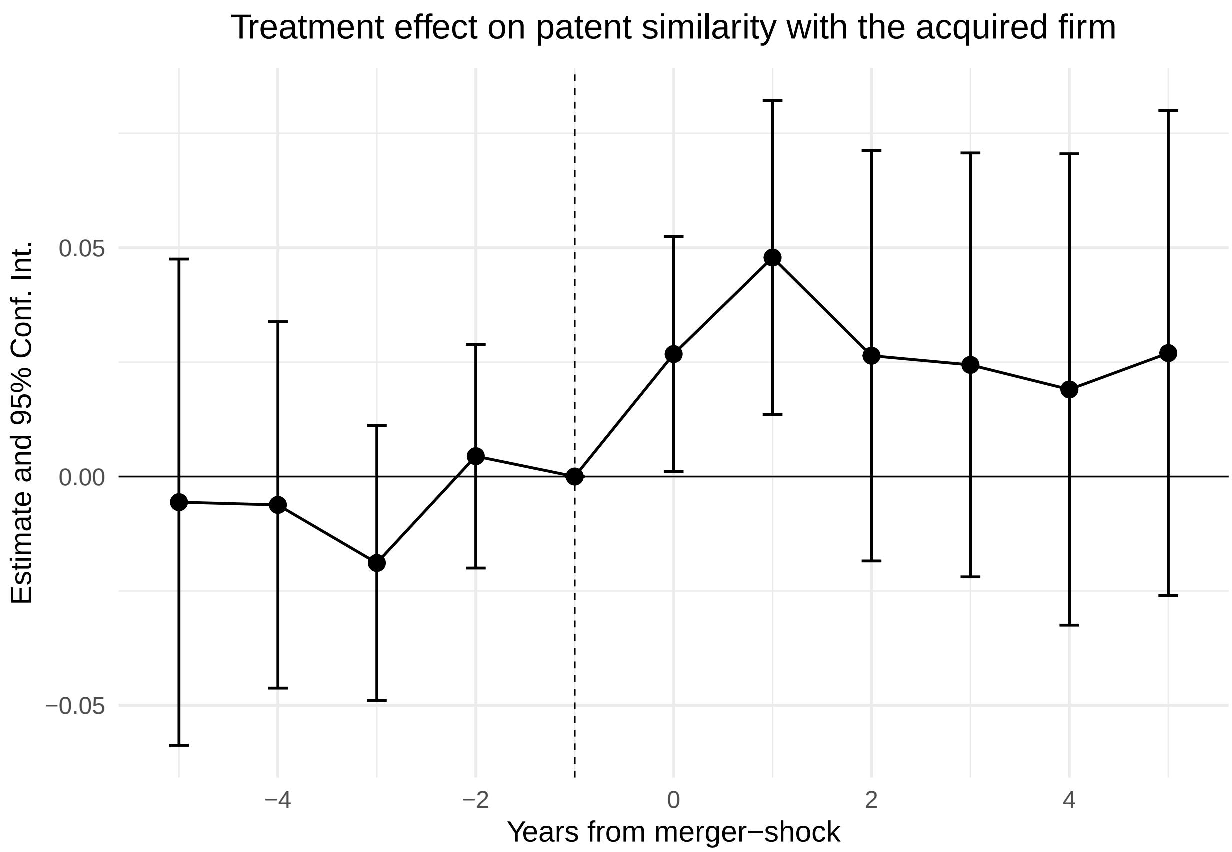

Figure 17: The effect of interlock severance on patenting similarity. The figure plots the relative-time × treatment regression coefficients, β_k, from Equation 11. The dependent variable is the correlation in patent distribution across classes between the shocked firm and the acquired, following Bloom, Schankerman, and Van Reenen (2013), corrected for dynamic heterogeneous treatment effects using the interaction-weighted estimator of Sun and Abraham (2021).

leading to better performance and output. The high resolution of patent subclasses within a firm allows me to address temporal unobservables not only at the firm level, but at the section and class levels as well, incrementally restricting the source of variation in patenting output to stem from differences across sections, class, and subclasses within a given firm and year.

First, I estimate the treatment effect at the highest definition, studying the effect of horizontal interlocks on subclass patenting output after losing an interlock with a subclass peer. Generally, we would consider firms as technological peers if they generate or hold patents in the same field of research. As the sample analog, I define the merger target firm as a *subclass peer* if it had any patents issued in the same subclass in the decade preceding the merger, and estimate Equation 12:

$$\begin{aligned}\text{Patents}_{jmt} = &\sum_{k=-5}^{5} \alpha_k \mathbb{I}[\tau_{jt} = k] \times \text{Peer}_{jm} \\ &+ \sum_{k=-5}^{5} \beta_k \mathbb{I}[\tau_{jt} = k] \times \text{Peer}_{jm} \times \text{Treat}_j \\ &+ \nu_{mt} + \xi_{jm} + \mu_{jct} + \varepsilon_{jmt}\end{aligned} \tag{12}$$

Where the subscripts s, c, and m index sections, classes, and subclasses, and Patents_{jmt} is the cumulative patenting output by firm j in subclass m in year t. I use two measures for output: the number and value of patents. $\mathbb{I}[\tau_{jt} = k]$ equals 1 if the relative-to-merger-shock year equals k, and 0 otherwise. Peer_{jm} equals 1 if firm j is merger-shocked by a peer in subclass m. Treat_j equals 1 if firm j loses a horizontal interlock due to a merger, and 0 if non-horizontal. ν_{mt}, ξ_{jm}, and μ_{jct} control for subclass-year, firm-subclass, and firm-class-year fixed effects, and $\varepsilon_{jmt} \sim N(0, 1)$ is an *iid* error term. The set of fixed effects ensures that the variation in patenting output does not stem from the fact that certain firms or fields may have abnormally productive periods, nor from any particular firm possessing certain subclass expertise.

Figure 18 reports the β_k coefficients from Equation 12 - estimated using the cumulative number of patents in the left panel, and the cumulative value of patents in the right panel, as the dependent variable. This model specification captures the treatment effect at the highest definition, comparing output at the subclass level across firms which only vary by the loss of a horizontal interlock. ν_{mt} controls for time-varying unobservables at the subclass level, addressing concerns of merger endogeneity, such as the possibility that the field is in decline and the merger is a response to that. ξ_{jm} controls for time-invariant subclass unobservables within the firm, like idiosyncratic productivity, that may naturally determine patent output.

I find that treatment decreases subclass output both in terms of patent count and patent value. In both cases we observe a relatively stable and flat pre-trend, with a decline in the post period. Over a span of five years, affected subclasses under-perform their neighbors — unaffected subclasses in the same class — by about 7 patents, or 216 million USD in innovation value. The effect is gradual, as expected, and peaks at year three, stabilizing around the new level in the following periods.

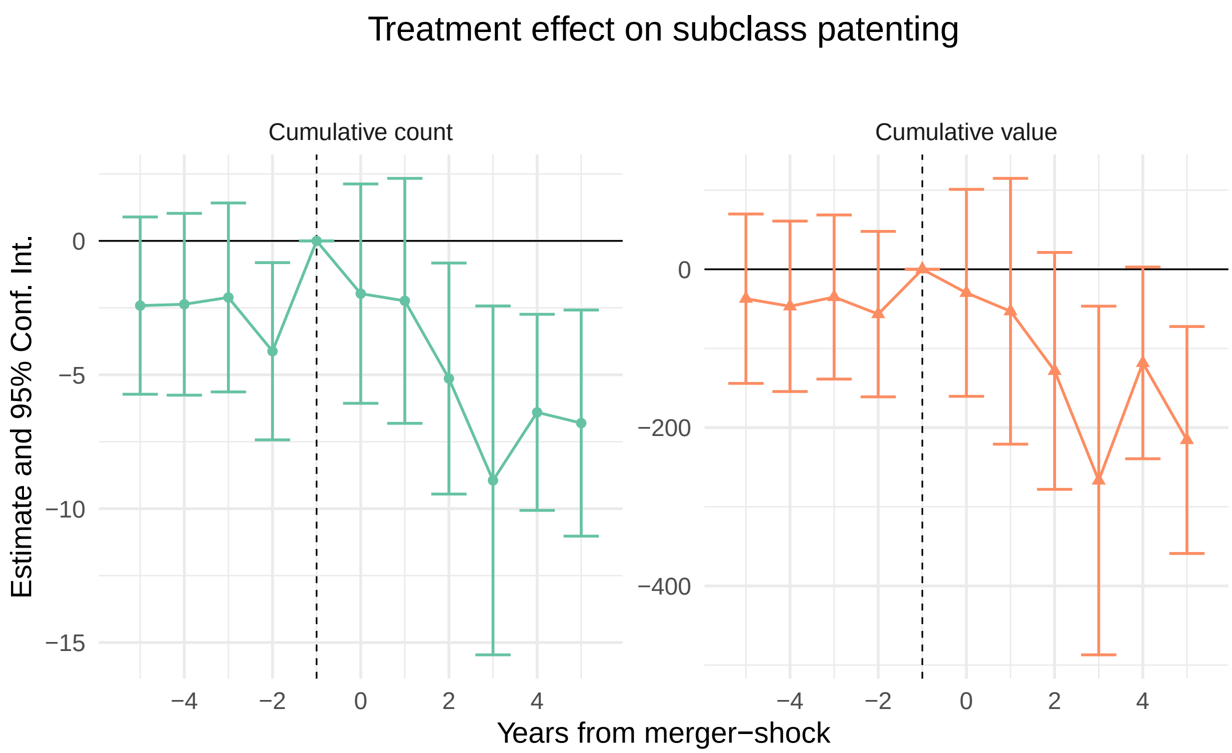

Figure 18: The effect of horizontal interlocks on patenting output at the subclass level. The figure plots the β_k coefficients from Equation 12. The dependent variable is the cumulative number of patents in the left panel, and the cumulative value of patents in the right panel - both at the firm-subclass-year level. The estimation includes fixed effects at the subclass-year, firm-subclass, and firm-class-year levels. Standard errors are clustered by firm-year.

Next, I exploit the full nested structure of patent classification, and explore the spillover effect across neighboring subclasses. I relax the model specification of (12) and allow output to also vary across subclasses, classes and sections, rather than only within subclass-year. I estimate Equation 13:

$$\begin{aligned}\text{Patents}_{jmt} = &\sum_{k=-5}^{5}\left[\mathbb{I}[\tau_{jt}=k]\times\left(\alpha_k^{section}\text{Peer}_{js}+\alpha_k^{class}\text{Peer}_{jc}+\alpha_k^{subclass}\text{Peer}_{jm}\right)\right]\\ &+\sum_{k=-5}^{5}\left[\mathbb{I}[\tau_{jt}=k]\times\left(\beta_k^{section}\text{Peer}_{js}+\beta_k^{class}\text{Peer}_{jc}+\beta_k^{subclass}\text{Peer}_{jm}\right)\times\text{Treat}_j\right]\\ &+\mu_{jt}+\nu_{mt}+\xi_{jm}+\varepsilon_{jmt}\end{aligned} \tag{13}$$

Patents_{jmt} is the cumulative patenting by firm j in subclass m and year t; $\mathbb{I}[\tau_{jt}=k]$ equals 1 if the relative-to-merger-shock year equals k, and 0 otherwise. Peer_{jm} equals 1 if firm j is merger-shocked in subclass m, i.e., if it loses an interlock with a firm that patents in that subclass; Peer_{jc} and Peer_{js} are similar indicators at the class and section levels. μ_{jt}, ν_{mt}, and ξ_{jm} are firm-year, subclass-year, and firm-subclass fixed effects, and $\varepsilon_{jmt} \sim N(0,1)$ is an *iid* error term.

Figure 19 plots the β_k coefficients of Equation 13, measuring the effect of rival interlock severance at different distances in technology-space on cumulative patent count. All coefficients across the three panels are estimated jointly but displayed separately for clarity.

Panels A through C summarize the dynamic treatment effect at the section, class, and subclass levels, corresponding to parameters $\beta_k^{section}$, β_k^{class}, and $\beta_k^{subclass}$. The section level in panel A captures the effect of losing an interlock with a rival who is a section peer, but not a class peer; for example, a firm patenting in organic chemistry (class C07) and severed from an industry rival patenting in inorganic chemistry (class C01), both grouped under chemistry (section C). The class level in panel B captures the effect of losing an interlock with a rival who is a class peer, but not a subclass peer; for example, nuclear reactors (subclass G21C) and nuclear power plants (subclass G21D), both under nuclear physics (class G21). Panel C captures the treatment effect at the subclass level: losing an interlock with a rival who is a subclass peer.

Overall, I find no significant effect of horizontal interlocks on the number of patents outside of the treated subclasses: Comparing the three panels, we see that the effect is almost entirely driven by having the horizontal interlock with a peer at the subclass level. At the subclass level, patenting steadily drops in the post-treatment years by a total of 13 patents after five years. This is equivalent to about two years worth of patenting, or 40% of output, on average. At the class and section levels, the estimated effects are generally positive, yet relatively small in magnitude and, for the most part, statistically insignificant. At the section level, the effects are similarly small in magnitude and statistically insignificant, though negative in sign.

A concern with studying R&D output using the number of patents as the measure of output is that a decrease in patent count may not necessarily indicate a reduction in innovation or

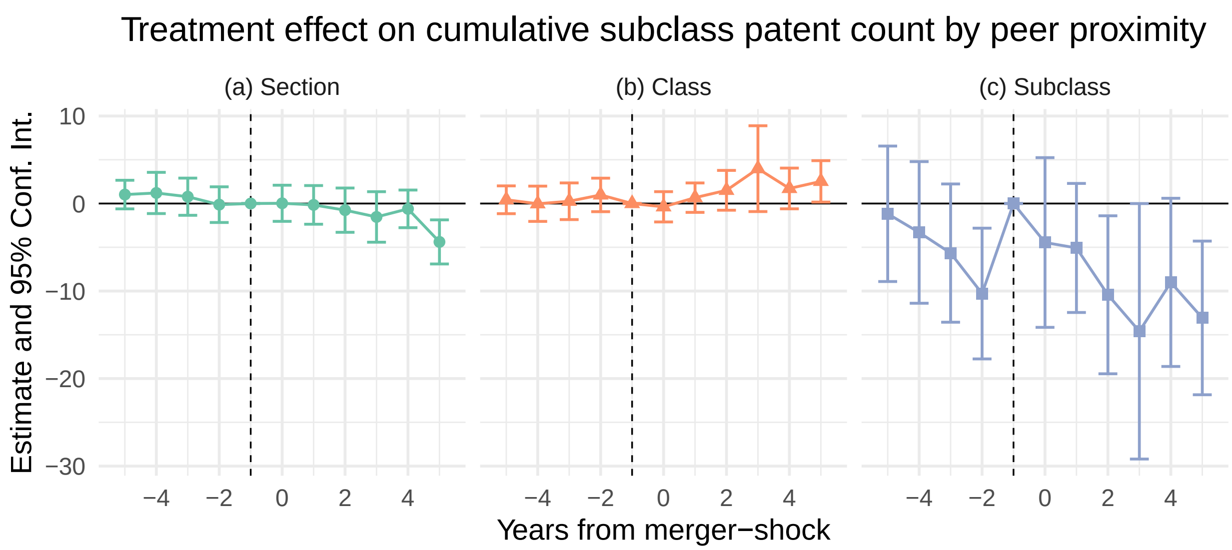

Figure 19: The effect of horizontal interlocks on patenting quantity by technological proximity. The figure plots the β_k coefficients from Equation 13. The dependent variable is the cumulative number of patents at the firm-subclass-year level. The estimation includes fixed effects at the firm-year, subclass-year, and firm-subclass levels. Standard errors are clustered by firm-year. All coefficients are estimated jointly and split into panels for convenience.

R&D activity. It could be that firms concentrate resources to produce fewer patents but of higher quality. I show this is not likely the case in Figure 20, which plots the estimated β_k coefficients of (13) using the cumulative value of innovation by subclass as the dependent variable. Innovation value is measured following Kogan et al. (2017), and converted to 2023 terms using the CPI.

The general pattern is similar to the count data with a decline on the order of 413 million USD, or two-thirds, in subclass value over five years. Class-level patenting slightly increases, while section-level slightly decreases - both mostly statistically insignificant. In a similar analysis, not reported here, I find that innovation value per patent drops as well, by 10-20 million USD at the end of the period. These results indicate a decline not only on the extensive margin - the scope of subclass patenting, but also on the intensive margin - the value of each patent.

My findings suggest that scientific knowledge generates synergies and positive spillovers in a neighborhood of technology space: two technologically similar firms have a lot to gain from private information, as one does not need to rerun experiments the other has already carried out, which reduces redundancy and research costs and improves productivity. When such a channel is lost, scientific output suffers directly.

On a broader scale, the section and class coefficients provide some insight regarding substitution patterns of internal firm resources: when interlocks are severed, companies may reallocate equipment and personnel within their R&D departments in response to changes in synergies and information availability. If synergies exists within a patent class, a shock to one subclass could spill over to adjacent subclasses. The intuition is that when certain projects are scaled down, the freed physical and human capital may benefit neighboring projects more than distant ones: it is usually more efficient to reassign a chemist to a different chemistry lab than to a physics lab. The somewhat weaker evidence at the class level seems to suggest that is so. When a subclass is "hit", its nearest subclasses slightly benefit: subclasses which lose a class peer, but not a subclass peer, tend to over-perform in terms of patenting output in the post-period. This could be a result of capital expenditure or personnel cuts at the subclass level, cannibalized by adjacent subclasses.

Taken together, my results using the three margins of treatment confirm that both information relevance and the competitive setting play an important role in the impact of interlocks on innovation. First, all the peer effects — denoted by the α_k coefficients — are small in magnitude and mostly statistically insignificant. This fact indicates that losing an interlock with a technological peer does not significantly affect patenting output on its own, which is consistent with directors not being the sole channel of communication. Non-rival firms usually face lower barriers to communication and cooperation on R&D, making the loss of one channel not very meaningful, regardless of how technologically close the two firms were.

Second, the competitive effect is significant and generally concentrated at the individual subclass level, with slight spillovers to adjacent subclasses across classes or sections. This means that losing ties with a rival firm that is also a close peer is especially detrimental to patenting output: in the case of firms in the same sector, formal cooperation could come under regulatory scrutiny and horizontal directors may play an important role in facilitating the exchange of information.

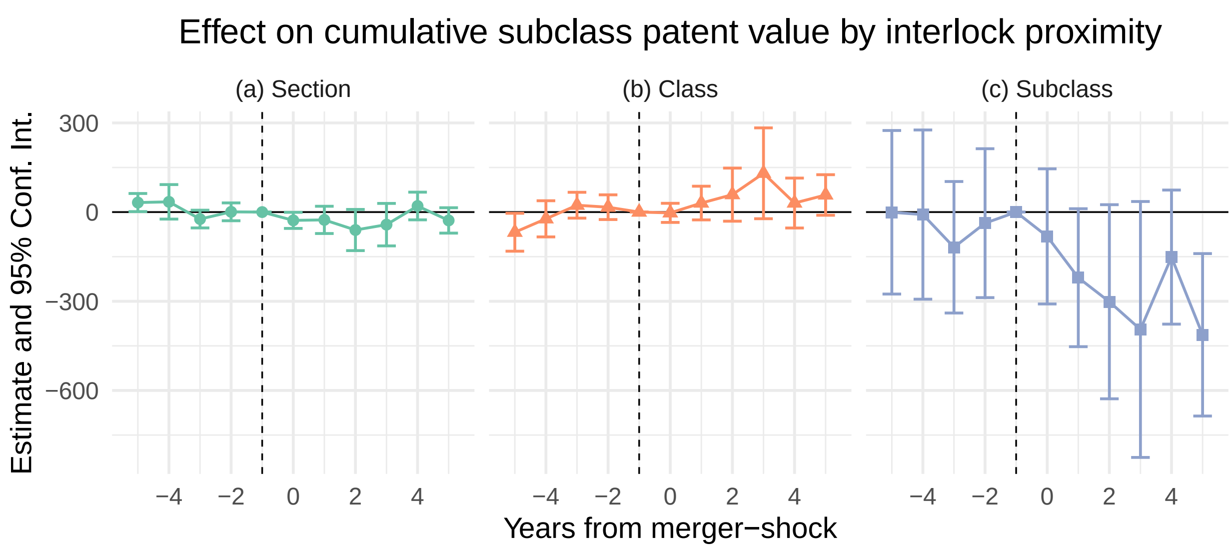

Figure 20: The effect of horizontal interlocks on patenting value by technological proximity. The figure plots the β coefficients from Equation 13. The dependent variable is the cumulative value of patents at the firm-subclass-year level, in 2023 USD. The estimation includes fixed effects at the firm-year, subclass-year, and firm-subclass levels. Standard errors are clustered by firm-year. All coefficients are estimated jointly and split into panels for convenience.

The evidence in this section suggests that directors can function as conduits of information across firms. When that information is both relevant and otherwise inaccessible, the interlock increases innovation. I show this using patent output, but one may be concerned that scientific advances are irrelevant to many firms and industries, such as retail or real estate, where there are no R&D synergies to realize. Indeed, large sectors of the economy do not engage in any R&D or patenting. However, there is nothing inherently specific to scientific knowledge in the proposed channel, allowing the results to generalize to any informational domain. If directors use superior information to influence patenting, it does not require a great leap of faith to imagine that they are similarly able to steer market entry, hiring policies, or overall business strategy.

8 Conclusion

Horizontal directors hold multiple board seats within a sector, offering superior expertise and knowledge, together with a coordination channel between rivals. This paper studies the effect of horizontal interlocks on firm performance and innovation. This question has concerned policymakers for over a century and is again relevant today, in the wake of renewed enforcement efforts by the Department of Justice and Federal Trade Commission. Using firm mergers as exogenous shocks to the network structure, I disentangle the network and coordination effects and find that horizontal interlocks increase returns by 3 percentage points. I show that horizontal interlocks decrease uncertainty and that firms tend to expand their boards and create new horizontal interlocks after one is severed. As the underlying mechanism, I suggest a channel of knowledge spillover, where informed directors steer firms away from directly competing with each other when the winner takes all and losses are costly, and illustrate the driving forces in the framework of a stylized model. Using data on patenting, I show that interlocks help firms avoid direct competition and increase innovation quantity and quality by 15 to 35 percent, at the slight expense of adjacent research fields in technology space.

Given the empirical setting, we may be tempted to conclude that horizontal interlocks are not only beneficial to firms, but also welfare-improving overall, since they allow for coordination that increases innovation and reduces redundancy - both generally desireable. I caution against such a conclusion, as the overall effect would heavily depend on context. Horizontal directors can just as easily serve as the mechanism that segments markets and stifles competition, as they can be the conduit of information that increases innovation. The effect of interlocks on welfare is likely to be highly heterogeneous across industries and sectors, and the optimal policy response would vary accordingly.

Finally, I highlight an overlooked aspect of mergers - severance of ties among incumbent firms. This paper only considers mergers as a source of exogenous variation in the network structure, but it may also have implications with respect to merger enforcement. Counter-intuitively, it could be that in industries where horizontal interlocks allow the exercise of market power, mergers are welfare-improving, as they disrupt coordination among incumbents. Therefore, the optimal merger control would in fact be more lenient.

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