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董事會連結網絡與數位創新之關係

Board Interlock Network and Digital Innovation

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Board Interlock Network and Digital Innovation

本論文係陳怡蓁君（學號 R09725018）在國立臺灣大學資訊管理學系、所完成之碩士學位論文，於民國 111 年 7 月 21 日承下列考試委員審查通過及口試及格，特此證明

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摘要

現今許多公司正在追求數位創新，然而，董事會對數位創新的影響卻尚未明瞭，為了解決這個研究缺口，本研究著重於董事會的連結網絡中心性，也就是董事會成員連結到其他公司董事會的程度，對數位創新的影響。根據社會資本理論，本研究主張連結網絡越中心的董事會，越能夠享有資訊利益，創造更多數位創新的機會。而利用動機-機會-能力模型，我們更進一步主張董事會的兩個領導方面的因素會影響上述關係，董事會內部領導力和董事會資訊科技領導力。

為了檢驗假說，本研究收集 2009 年至 2014 年，在資訊與通信產業的公司資料，包括從 BoardEx 資料庫收集董事會有關的資料，從 NBER 收集有關專利的資料，以及從 Compustat 收集公司金融相關的資料。本研究結果顯示董事會連結網絡中心性正向顯著地影響數位創新，且此關係被董事會內部資訊科技領導力正向調節，但是被董事會內部領導力和董事會外部同產業領導力負向調節。

關鍵字：數位創新、公司治理、董事會連結、董事會連結網絡、網絡中心性

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Abstract

Many companies are trying to apply digital innovation. However, the impact of boards on digital innovation, a top-down influence of a firm's leadership, has been overlooked. To address this gap, we focus on the effect of the firm's board interlock network centrality, the extent to which the board of directors is connected to boards of other firms, on its digital innovation. Based on social capital theory, we propose that board interlock network centrality provides firms with IT information benefits, creating opportunities to develop digital innovation. Applying the motivation-opportunity-ability model, we further propose that the two aspects of board leadership moderate this relationship: internal (vs. external) leadership and IT leadership.

To examine our hypotheses, we collected board data from *BoardEx*, patent data from *NBER*, and financial data from *Compustat* of firms in the ICT industry from 2009 to 2013. Our results show the significant and positive relationship between board interlock network centrality and digital innovation, and this relationship is positively moderated by IT internal leadership. Yet, the effect is weaker when firms have high internal leadership and external intra-industry leadership.

Keywords: digital innovation, corporate governance, board interlocks, interlock network, network centrality

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1 Introduction

1.1 Background

More and more companies are pursuing information technology to achieve their business goals. For example, many firms try to predict future trends, such as what customers will like, by machine learning technology with tens of thousands of users' data to increase their market share. Therefore, digital innovation increases rapidly and has changed the face of business when companies intend to use information technology to solve problems and improve competitiveness (Demirkan et al., 2016; Fichman et al., 2014). Based on the 2021 Digital Business Study published by the International Data Group (IDG), most organizations (91%) have adopted or plan to adopt a "digital-first" business strategy. To do so, organizations plan to spend an average of $16.5 million on digital initiatives, investing in new technologies such as artificial intelligence, machine learning, and data analytics. We have entered a golden age of digital innovation (Fichman et al., 2014).

However, digital innovation is riskier than traditional innovation due to rapid and complex control over information technology. Prior research has examined firms' difficulties in developing digital innovation (Nylén & Holmström, 2015; Ravichandran, 2018). Nylén and Holmström (2015) argue companies cannot evaluate

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the value generated by digital technology investments. Ravichandran (2018) indicates that not much work has been done for firms in exploring the necessary capabilities to leverage their digital platforms effectively. According to an annual report published by Everest Group in 2018, up to 73 percent of enterprises failed to provide any business value from their digital innovation process. As a result, it is necessary to explore what factors lead to digital innovation in firms due to its significant potential upsides and downs.

1.2 Research Objectives

In this research, we focus on one crucial dimension of firm management, the board of directors. We examine the top-down influence of the firm's board directors and its ties with other firms through board interlocks on digital innovation. We propose that interlocks between a firm's board directors and other firms' board directors affect the focal firm's digital innovation.

The first objective of this research is to investigate how the IT resources obtained through board members' interlocks influence the firm's digital innovation. Prior research has focused on the influence of internal firm structure on digital innovation, but the effect of external social capital of the board remains unclear. Chen et al. (2021) and Li et al. (2021) examine how CIOs lead their firms' digital innovation.

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Choi et al. (2021) note the relationship between the CEO and digital innovation. However, little work has investigated the board's influence on digital innovation, while board members can set the tone and provide critical resources through interlocks. We examine how external resources gained through board interlocks influence digital innovation. Moreover, we approach the issue from the social network perspective. The social network approach is important because we can see the position of a firm in a network. We focus on one important dimension of social network of board members, board interlock network, and measure it by network centrality. We propose that board directors will get IT information benefits through interlock network based on social capital theory and thus enhance digital innovation in their firms.

The second objective of this article is to investigate the moderating effects of the leadership on the relationship between board interlock network centrality and digital innovation. The outcome differs in the extent of social actors' motivation and ability to engage in information exchange when they have opportunities (Rindfleisch & Moorman, 2001). According to the motivation-opportunity-ability (MOA) theoretical framework, the result will be stronger when managers are more motivated and able to translate knowledge into innovation (Srinivasan et al., 2018). We propose that two aspects of leadership on the firm's board will affect the extent to which IT knowledge

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is shared and acted by its managers to develop digital innovation, internal (vs. external) leadership and IT leadership.

1.3 Contribution

This study makes several contributions. First, we contribute to the literature on digital innovation by examining the top-down impact of board interlock networks, an issue that has been overlooked in the management literature. Second, we show that aspects of board leadership, including internal (vs. external) leadership and the presence of IT executives, moderate the effect of board interlock centrality on digital innovation. Our findings on the impact of IT leadership on the board provide a novel extension to the literature on the influence of IT leadership on firm performance. Third, we contribute to the literature on board interlocks by examining their impact on digital innovation, a key adaptation mechanism that has not been examined in the literature. Finally, we aim to provide insight for managers and board of directors on what influence digital innovation and how to enhance it.

2 Literature Review

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2.1 Social Capital Theory

Social capital theory has been developed from sociology literature and applied to many disciplines to explain a wide range of social phenomena (Portes, 2009). Social capital is identified as the goodwill available to individuals or groups, whose source lies in the structure and content of the actor's social relations (Adler & Kwon, 2002). The fundamental proposition of social capital theory is that social capital constitutes a valuable source of information benefits. Information benefits occur in three forms: access, timing, and referrals (Burt, 1992). Access refers to receiving a valuable piece of information; timing refers to the ability of contact can make the actor in the network informed early; referrals are those processes providing information on available opportunities to people or actors in the network.

When getting information benefits through social capital, the new intellectual capital of actors will increase. Nahapiet and Ghoshal (1998) argue the mechanism of how social capital facilitates the creation of new intellectual capital based on social capital theory. Intellectual capital is a valuable resource and a capability for action based on knowledge and knowing (Nahapiet & Ghoshal, 1998). According to Moran and Ghoshal (1996) 's model, all new resources, including intellectual capital, are created through combination and exchange. Therefore, new intellectual capital is created through the combination and exchange of the resources gained from social

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capital. That is, social capital constitutes a valuable source of information benefits, influencing access to parties for combining and exchanging knowledge, thus creating new intellectual capital (Burt, 1992; Nahapiet & Ghoshal, 1998).

2.2 Digital Innovation

Digital innovation is defined as a product, process, or business model perceived as new and embodied in or enabled by IT (Fichman et al., 2014). It includes initiating, developing, implementing, and exploiting (Kohli & Melville, 2019). According to the research of Nahapiet and Ghoshal (1998), where they identify innovation as a radical change of intellectual capital, digital innovation is a radical change of IT intellectual capital. That is, companies make new combinations of IT knowledge incrementally or radically, thus developing digital innovation.

In order to find what impacts digital innovation, most studies have focused on the interaction between a firm's internal factors and digital innovation, such as a firm's executives, capabilities, or environment. For example, Choi et al. (2021) examined the positive influence of a CEO's risk-taking incentives on digital innovation. Chen et al. (2021) found that the effectiveness of CIO issue selling positively impacts digital innovation success. Firk et al. (2022) investigated the relationship between the digital knowledge of the top management team (TMT) and

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digital innovation. Nasiri et al. (2020) found four digital-related capabilities of a firm shape the exploitation of digital innovation. Dery et al. (2017) suggest digital workplace plays a key role in digital innovation.

Although the above-mentioned studies have suggested the importance of the relationships between a firm's internal factors and digital innovation, relatively few studies have examined the interaction between external resource brought by corporate board and digital innovation.

2.3 Corporate Board

In this research, we focus on the relationship between corporate board and digital innovation because, in accordance with agency theory and resource dependency theory, board of directors can influence firm innovation (Jaskyte, 2012; Wu & Lee, 2007). Based on agency theory, board of directors can identify problems and opportunities or provide advice and guidance on behalf of stakeholders (Hillman & Dalziel, 2003). According to resource dependency theory, they can also acquire different resources needed to foster and support innovation (Jaskyte, 2012).

Previous research has examined the influences of board composition on firm innovation. Some scholars argue that the demographics of board directors affect innovation in companies. For example, Galia and Zenou (2012) found gender and age

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diversity of board directors is positively related to a firm's innovation. Some researchers examine the impact of board directors' human capital on firm innovation. For example, Wu (2008) claim that company-specific knowledge and board member experience positively relate to firm innovation performance. In this article, we focus on a critical dimension of board composition, namely, external social capital.

2.4 Board External Social Capital

Management literature has adopted the concept of social capital to explain the benefits of board social networks since the early 2000s (Adler & Kwon, 2002; Kim, 2005). Kim and Cannella (2008) identify board social capital as the interpersonal linkages between individuals inside and outside the firm that are important to boards. They divide social capital into internal and external social capital based on connections inside or outside the organization. In this article, we focus on board external social capital since it is proved an important input to the board's innovation advising function (Srinivasan et al., 2018). Board members with external linkages help transmit tacit knowledge and expose firms to relevant information, thus helping innovation performance in firms (Chuluun et al., 2017).

We identify board external social capital as resources obtained via board interlock network. External board social capital derives from a board member's

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contacts with external stakeholders such as suppliers, clients, investors, political elites, and other business leaders. And it is established in several ways, such as personal relationships, social standings, and seats on other boards (Barroso-Castro et al., 2015; Kim & Cannella, 2008). Following previous studies (Chuluun et al., 2017; Sauerwald et al., 2016; Wincent et al., 2010), we regard external board social capital as the directors' social network through board interlocks (directors on the board of one firm also sit on the board of other firms). A board interlock network is a major source of a board's external social capital and is proved to positively impact firm performance because interlocking directorates can provide management with access to a variety of key resources (Barroso-Castro et al., 2015).

2.5 Interlock Network Centrality

In social network literature, network centrality is most commonly studied and widely used to capture a firm's access to other actors in a social network (Chuluun et al., 2017; Larcker et al., 2010). Prior research has shown that interlock network centrality affects information access and thus impacts innovation (Wang et al., 2015), but the effect on digital innovation remains unknown. Hence, we explore whether the firm's central position in the interlock network enhances digital innovation.

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2.6 MOA model

The motivation-opportunity-ability (MOA) model is well established in management literature to explain human behavior, such as knowledge-sharing among employees (Siemsen et al., 2008). Motivation refers to the individual or organization's desire to act; opportunity represents the environmental or contextual mechanism that enables action; ability captures skills or knowledge base related to the activity.

Prior research has examined how motivation, opportunity, and ability of executives or board members affect the relationship between network and firm performance. Wang et al. (2017) argue the positive impact of the firm information reach through top marketing and sales executives' mobility network on firm market valuations will be stronger when their executives are motivated and have more abilities. Srinivasan et al. (2018) propose the positive effect of the firm's board interlock network on new product introductions will be stronger when its board of directors are motivated and able to translate the acquired market intelligence into new products. In summary, motivation, opportunity, and ability are essential factors for board directors to change their behaviors.

3 Research Hypothesis

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3.1 Research Model

Our research model in Figure 1 adapts the model of Srinivasan et al. (2018) to our study context. As we noted previously, Srinivasan et al. (2018) focus on the board interlock network and new product introductions, offering a model where the board interlock network centrality is an independent variable and new product introductions is a dependent variable. They also integrate the MOA model and show that internal (vs. external) leadership and marketing leadership on the board moderate the effect. Their model explains well how firms obtain marketing information advantages through interlock networks to boost intellectual capital. In this article, we expand the model under the IT scenario. The dependent variable in our model is digital innovation, and the independent variable is board interlock network centrality. We also adapt the MOA model and propose that the relationship will be stronger when there are internal leadership and IT leadership on the board. However, the effect is weaker when intra-industry external leadership is on the board.

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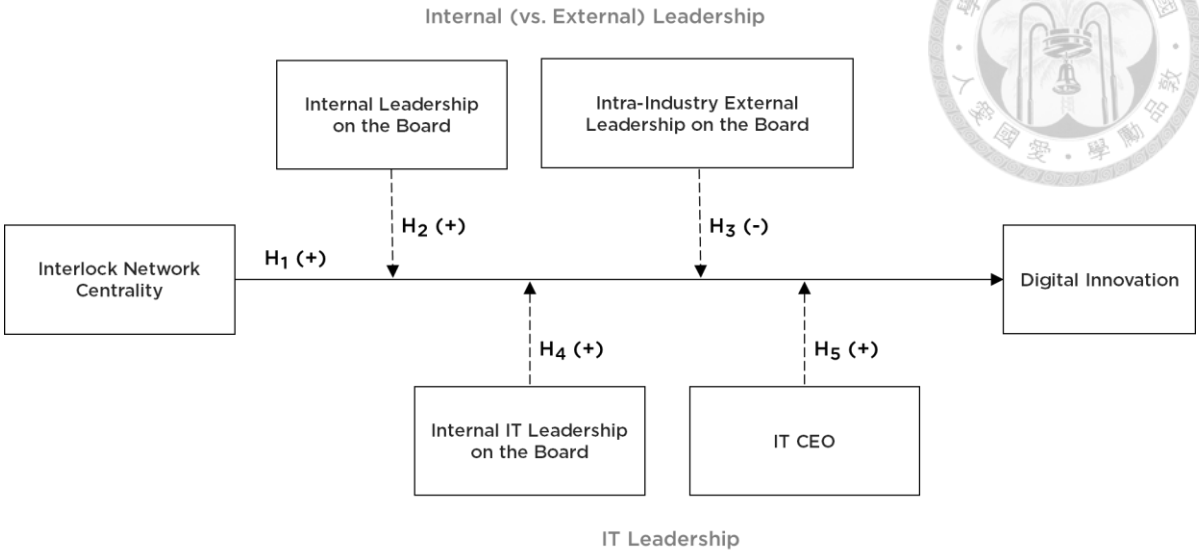

Figure 1 Research Model

3.2 Main Effect of Board Interlock Centrality

Based on the social capital theory mentioned in the literature review, we propose that a firm's external social capital through interlock networks positively influences its IT intellectual capital, digital innovation. Being central in interlock network gets IT information benefits, which helps firms to combine and exchange IT resources and thus enhance digital innovation.

3.2.1 Centrality and IT information

The more central the firm's position in the interlock network, the greater IT information benefits it can get. Burt (1992) suggests information benefits occur in three forms: access, timing, and referrals. Access refers to receiving a valuable piece

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of information. Being the central of interlock network, the firm can access a wide range of valuable information, especially about IT knowledge. Timing refers to the ability of contact to inform the actor in the network early. The firm get the latest IT information when it is in the central position of interlock network. Referrals are those processes providing information on available opportunities to people or actors in the network. Contacts get the firm mentioned at the right time in the right place, so opportunities are presented to it. That is, a firm in a central position of a network means it is more important or has a higher power and prestige, so IT interlock partners are more willing to exchange with it (Larcker et al., 2010; Wang et al., 2015). Moreover, the non-interlock IT firms may be aware of the central actor and have cooperation, interaction, or any other activities with it in the future. To sum up, a firm in a central position of a network can get IT information benefits, including a wide range of IT information, the latest IT news, and many opportunities of interaction with other IT firms.

3.2.2 IT Information and Digital Innovation

Nahapiet and Ghoshal (1998) note that creating knowledge involves making new combinations, and exchange is a prerequisite for resource combination. A centrally connected firm in an interlock network enjoys more IT information benefits,

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including a wider range of IT information, more efficient access to IT resources and greater opportunities to interact with other IT parties. These IT information benefits give central firm exposure to the latest IT environment and make board members more familiar with IT knowledge. Therefore, the board can make better IT decisions and strategies. Prior research has shown that because of greater access to information, the board in the central position of a network increases firm performance in respect of innovation (Chuluun et al., 2017), marketing (Srinivasan et al., 2018), and finance (Guo et al., 2021). Consequently, we propose that the firm's interlock network centrality with the high IT information benefits will stimulate digital innovation. Thus, we hypothesize:

H_1: Firm's board interlock network centrality positively impacts digital innovation

3.3 Moderating Effects of leadership on the Board

Although a firm's board interlock network centrality increases its access to IT information, it merely provides an opportunity for the firm to develop digital innovation. Srinivasan et al. (2018) claim a contingency model and identify interlock centrality as an opportunity of stimulating new product introductions. Internal (vs. external) leadership profile and marketing leadership on the firm's board moderate the

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relationship between board interlock centrality and new product introductions because the main effect will be stronger when senior managers are motivated and have the appropriate ability.

Drawing on Srinivasan et al. (2018) 's model, we further propose that Internal (vs. external) leadership and IT leadership on a firm's board of directors moderate the extent to which IT information accessed through the interlock network is identified, applied, and acted by the board to develop digital innovation.

3.3.1 Internal (vs. External) Leadership on the Board

Whether a firm is motivated and able to translate opportunities from the received IT information benefits into digital innovation depends on the board's internal leadership. We first consider the proportion of internal board members who are also executives in a firm. Then, we include the proportion of external board members from the same industry.

We identify internal leadership on the board as the extent to which board members are also senior executives in the firm (i.e., inside directors). Senior executives are well-formed about their firm's resources and thus reach consensus among senior management more efficiently and effectively (Srinivasan et al., 2018). Moreover, because of inside directors' knowledge of day-to-day operations, they can

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enhance board decision making and develop more feasible digital innovation (Harris & Shimizu, 2004). For example, when a firm becomes aware of big data analysis via the interlock network, it is more effective to implement it for the board, which consists of more internal board members. Therefore, we propose that when internal leadership on a firm's board rises, IT information benefits obtained from the interlock network may be more effectively leveraged, thus increasing digital innovation. Thus, we hypothesize:

H_2: The firm's internal leadership on the board enhances the relationship between its interlock network centrality and digital innovation.

A firm's IT information benefits obtained from the interlock network may be limited if the external board members (i.e. outside directors, independent directors) are from other firms but within the same industry. First, external board members have a fiduciary duty to the firms on whose boards they serve (Srinivasan et al., 2018). They may be less motivated to share IT information on the board, preventing violation of the fiduciary duty of other firms. The motivation of external board members in other industries does not affected by such fiduciary duty because firms they serve does not compete with the focal firm now or in the future, so they are more willing to share IT information.

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Second, a firm's external board members within the same industry may be less able to provide useful IT information beyond what the firm already knows. Their industry experiences overlap with those of internal board members or senior executives. The resources they provide, including IT information, may be similar to what internal board members or senior executives already have obtained. Moreover, when a firm's board has more external directors from the same industry, it may be victim to group or myopia and obstacle to the development of digital innovation. However, the external board members from different industries provide more diverse resources and increase the firm's cognitive scope, so external board directors will not have those concerns. In summary, although external directors contribute to monitoring managers and protecting the interest of stakeholders, those within the same industry may weaken the effect of interlock network centrality on digital innovation. Thus, we hypothesize:

H_3: The firm's external leadership on the board within the same industry diminishes the relationship between its interlock network centrality and digital innovation.

We do not formulate the third category, external board members from a different industry, because the sum of the proportion of internal directors, external directors

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within the same industry, and external directors from other industries is one. The first two proportions have elaborated in H_2 and H_3.

3.3.2 IT Leadership on the Board

Functional background, defined as the functional area in which an actor has spent the most time, frequently be used as indicator of cognitive and value-based filters (Cannella Jr et al., 2008; Manner, 2010). When board members with IT backgrounds, they are more motivated and have more ability to develop digital innovation. Prior research has shown that a board with IT functional background result in a better firm performance (Héroux & Fortin, 2018; Zhang et al., 2016). Therefore, we propose that the positive effect of a firm's board interlock centrality on digital innovation will be stronger when the board members with IT background (i.e., IT leadership on the board). We divide IT leadership on the board into two aspects, internal IT leadership and the presence of a CEO with IT background.

We identify internal IT leadership as the number of senior IT executives on a board. Senior IT executives, such as CIOs, CTOs, or CDOs (Chief Digital Officers or Chief Data Officers), are uniquely positioned to process IT information obtained from interlock networks. First, with technological expertise and experience, senior IT executives can judge the quality and feasibility of IT information gained via the

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interlock network. Hence, they pay more attention to and value the IT information benefits obtained through the interlock network on the board. Then senior IT executives can utilize that information to evolve digital innovation because they possess the knowledge schemas in the firms. Furthermore, senior IT executives on the board can also help other board members understand the firm's technological capabilities and resources (Li et al., 2021). In this situation, other board members are more willing to share IT information obtained from the interlock partners in the boardroom. Thus, we hypothesize:

H_4: The firm's internal IT leadership on the board enhance the relationship between its interlock network centrality and digital innovation.

Given their formal and symbolic power, CEOs significantly impact both organizational activities and performance (Rajagopalan & Datta, 1996). The functional background of CEOs affects their interpretation of the situation and what is "important" (Finkelstein & Hambrick, 1990). Thus, a CEO with an IT background may put the firm's emphasis on IT areas to secure competitive advantages. The directors on such a board are more motivated to share IT information obtained from the interlock network and the executives are more motivated to leverage the IT information into digital innovation. Moreover, CEOs with IT expertise are likely to be more effective in their firm-wide IT risk management responsibilities and policies

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(Haislip et al., 2021). They have the IT knowledge to improve IT governance of the board and help establish a digital environment, which is helpful to develop digital innovation. Thus, we hypothesize:

H_5: The firm's IT CEO enhance the relationship between its interlock network centrality and digital innovation.

4 Methodology

4.1 Data

We propose the IT information benefits sourced from a firm's board interlock network as the theoretical mechanism behind the effect of network centrality on digital innovations. Therefore, to test our hypotheses, we needed an industry in which information technology is emphasized. We focused on sectors in the ICT industry, including hardware components, hardware equipment, software, telecommunications, and media because these firms typically pay attention to the importance of employing IT information in operation and innovation (Basole et al., 2015; Li et al., 2021).

To construct our dataset, we identified companies in the ICT industry and collected related data from *Boardex*, National Bureau of Economic Research (NBER),

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and *Compustat* between 2009 and 2013[1]. We first extracted a list of companies in the ICT industry with SIC codes from *Compustat* and matched them with board data from *Boardex*. Second, we compared the company data with patent data from NBER. We further acquired financial data from *Compustat* and other online sources, such as company's official website. Our final panel dataset contains 1,324 firm-year observations covering 409 unique firms in our observation window (2009-2013).

4.2 Measures

4.2.1 Dependent Variable

The number of patents is considered the most common measure of innovation performance Sarto et al. (2019). Since the most important feature of digital innovation is successful generation of new IT-enabled innovation, such as products, processes, and services, we used IT patents to capture digital innovation and employed patent

[1] The U.S. Patent and Trademark Office (USPTO) required that patent system moved from the United States Patent Classification (USPC) system to the Cooperative Patent Classification (CPC) system in 2014. In previous literature, digital innovation is mainly identified as numbers of digital patents with USPC classification system. We also found that, the networks each year were similar during the time period, suggesting the stability of the ICT industry. Therefore, we chose our sample period to be 2009-2013. Year dummy variables was added in our model.

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technology classes to categorize IT patents. The patent technology classes we adopted in our research are in line with previous digital innovation research(Choi et al., 2021; Chung et al., 2019; Kohli & Melville, 2019).

The dependent variable is a firm's annual count of digital innovation, measured by the number of IT patents a year. We also used a one-year lag between our dependent variable (year t + 1) and other variables (i.e., independent and control variables, year t) to address concerns on reverse causality.

4.2.2 Independent Variable

We constructed annual board interlock networks to model IT information diffusion of firms. In an interlock network, vertices represent firms, and edges demonstrate interlock relationship (i.e., an edge is formed when a board member serves on the board of another firm). This measure of interlocks has commonly been used in the literature on boards (Chuluun et al., 2017; Harjoto & Wang, 2020; Larcker et al., 2010; Sánchez & Barroso-Castro, 2015).

We used eigenvector centrality to measure network centrality. Eigenvector centrality is a more sophisticated way to calculate centrality, which not only focus on how many relationship a firm has, but also on whom it is connected matters (Chuluun et al., 2017). Eigenvector centrality was calculated in the following steps (Bonacich,

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1972; Newman, 2008). Let $A = (a\_ij)$ be the adjacency matrix of interlock network in a specific year t, x_i denote the centrality of the i-th firm, and γ be a constant, and thus we had:

$$x_{it} = \frac{1}{\gamma} \sum_{j \neq i} a_{ij} x_j$$

Defining the vector of centralities $x = (x\_1, x\_2, \ldots)$, we rewrote this equation in matrix form as

$$\gamma x = Ax$$

Hence, we saw that x is an eigenvector of the matrix with eigenvalue γ. Finally, eigenvector centrality was the greatest eigenvector solution γ with nonnegative entries on the basis of the Perron–Frobenius theorem, thus we had:

(3) $$Eigenvalue_{it} = \max(\gamma)$$

The independent variable is *Eigenvalue*$_{it}$ in Equation 3 , the eigenvector centrality of firm i in year t. A firm connected to other more central firms has a higher value of eigenvector centrality. Figure 2 shows the interlock network of firms in the ICT industry in 2009. A node with darker color has a higher value of eigenvector centrality. Appendix lists all the interlock networks of firms in the ICT industry from 2009 to 2013.

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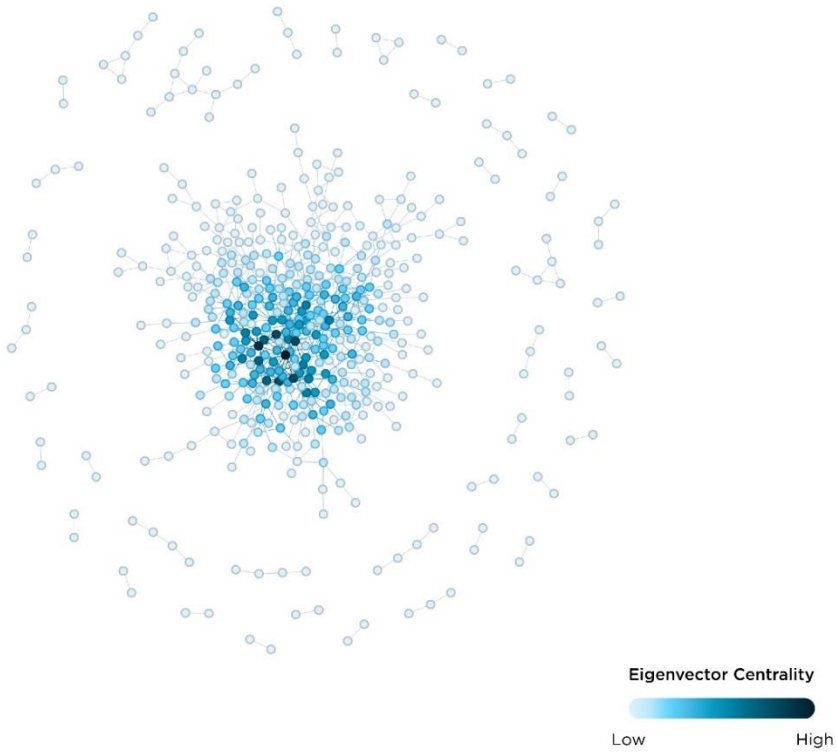

Figure 2 Interlock Network in 2009

4.2.3 Moderators

We measured internal leadership on the board (INLSP) by the proportion of internal board members (i.e., the number of directors on the board who are executives at that focal firm divided by the size of the board). We calculated intra-industry external leadership on the board (INEXLSP) by the proportion of external board members from firms in the focal firm's industry with the same four-digit SIC code.

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We coded internal IT leadership on the board (INITLSP) as the proportion of IT executives on the board. Consistent with prior research (Haislip et al., 2021; Van Peteghem et al., 2019), we identified IT executive with job titles containing the phrase "CIO", "CTO", "tech", "engine", "data", "software", "information", or "computer". IT CEO (ITCEO) was operationalized as a CEO with IT expertise. Prior research has found two ways to form a CEO's IT expertise power: IT education and IT experience (Lim et al., 2013). Following previous research(Haislip et al., 2021; Van Peteghem et al., 2019), we measured IT education as an academic degree in computer science or information system and IT experience as any previous position as IT executive. ITCEO was coded 1 if a CEO met the criteria for either IT education or IT experience, 0 otherwise.

4.3 Control Variables

We controlled for board-level, firm-level, and industry-level characteristics. Many studies find that older boards are less likely to initiate changes, but younger boards are associated with greater strategic change (Johnson et al., 2013). So, we controlled for *board age*, measured as the average age of a board. Prior research has also considered the positive influence of a board's size on firm performance (Barroso-Castro et al., 2015). We used *board size*, measured as the number of board members

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in a firm, as a control variable. A board can be structured around CEO in two ways in the United States. CEO can act as board chairman, in a duality position of chairman and CEO, or two different individuals can occupy the two positions. Prior research indicates that the CEO has more power in the dual structure than in the non-dual situation where the CEO shares power, which may affect the board structure (Stevenson & Radin, 2009). We controlled for *CEO duality*, measured as a dummy variable coded 1 if a CEO is also the chairman of the board and 0 otherwise.

Firm age and size affect a firm's ability to develop innovations, which are important control factors in board literature. We thus controlled for *firm age*, measured as the number of years since a firm's initial public offering (IPO) in accordance with previous research (Loderer & Waelchli, 2010), and *firm size*, measured by using the number of employees (thousands) in a firm. We also controlled for a number of accounting/financial variables to capture a firm's ability to undertake innovation activities such as *R&D expense*, *market-to-book ratio*, and *current ratio*. *R&D expense* is viewed as a firm's absorptive capacity and proved to have a significantly positive influence on innovation (Bhattacharya & Bloch, 2004). *Market-to-book ratio*, measured as the ratio of the market value of assets to the book value of assets, can capture a firm's future performance potential from the capital market perspective (Chen et al., 2005). We used firm *current ratio* to control for the

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availability of slack resources, which could increase exploratory and lead to greater innovative performance (Phelps, 2010).

We also included four digital SIC dummies in our model to control for industry-specific effects. Year dummies were also included to control for economy or market-related shocks that vary over time. The operationalization of the variables is described in Table 1.

4.4 Model Specification

We used the annual count of IT patents of firm i in year t as our dependent variable. The mean of the dependent count variable was higher than 4 (M=8.43), and data were overdispersed (SD=55.21). Therefore, we used a negative binomial regression approach, which accommodates count data with overdispersion (Ver Hoef & Boveng, 2007). We used one-year lagged values of our independent variables because it takes time for board members and CEOs to change R&D strategies and generate digital innovation (Choi et al., 2021). We also included industry- and year-dummy variables to control for unobserved industry-level and year-specific shocks. The model specification is as follows:

$$DI_{i,t+1} = \beta_0 + \beta_1 IC_{i,t}$$

$$+ \beta_2 INLSP_{i,t} + \beta_3 INEXLSP_{i,t} + \beta_4 INITLSP_{i,t} + \beta_5 ITCEO_{i,t}$$

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$$+ \beta_6(IC_{i,t} \times INLSP_{i,t}) + \beta_7(IC_{i,t} \times INEXLSP_{i,t})$$

$$+ \beta_8(IC_{i,t} \times INITLSP_{i,t}) + \beta_9(IC_{i,t} \times ITCEO_{i,t})$$

$$+ \Sigma\beta_j Controls_{i,t} + \tau_1 ID_{i,t} + \tau_2 YD_{i,t} + \varepsilon_{i,t}$$

where i denotes a firm, t denotes the year; β_1-β_j are parameters specifying the impact of independent variables and control variables; τ_1 and τ_2 are vectors of unknown parameters specifying the impact of industry dummies $ID_{i,t}$ and year dummies $YD_{i,t}$.

Table 1 Measures and Data Sources

Variables	Measures	Data Sources
Digital innovation	Number of IT patents of the firm in a given year	NBER
Interlock centrality	Eigenvector centrality of the firm in the board interlock network	BoardEx
Internal leadership on the board (INLSP)	Ratio of the number of directors on the board who are executives at the firm to the size of the board	BoardEx
Intra-industry external leadership on the board (INEXLSP)	Ratio of the number of directors on the board who are members at firms outside the firm but within the industry to the size of the board	BoardEx
Internal IT leadership on the board (INITLSP)	Ratio of the number of directors on the board who are IT executives in the firm to the size of the board	BoardEx

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IT CEO (ITCEO)	1 if the CEO has IT education or IT experience background, 0 otherwise	BoardEx
Average board age	The average age of board directors	BoardEx
Board size	Number of directors composing the board of directors	BoardEx
CEO duality	1 if the CEO is also the chairman of the board, 0 otherwise	BoardEx
Firm age	Number of years since the firm's ipo	Compustat
Firm size	Total number of employees in the firm (unit: $1,000)	Compustat
R&D expense	Total R&D expenses (unit: million $)	Compustat
Market-to-book ratio	Ratio of book assets minus book equity plus market equity, over book assets at the beginning of the year	Compustat
Current ratio	Ratio of the assets of the firm to its liabilities in	Compustat

5 Results

Table 1 lists the means, standard deviation, minimum values, maximum values, and correlations of the variables in our analysis. The correlations are all below 0.70[2].

[2] The maximum average board age is higher than 80 because two firms in our dataset each had only one board member whose age was higher than 80.

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The results of hypothesis testing are represented in Table 2. Model 1 is the baseline model with control variables. Model 2 tests H1 and Model 3 is the full model with all moderators.

We first report the tests of the hypothesis. We find support for H1, which posits a positive main effect of the firm's board interlock centrality on its digital innovation ($p < 0.01$). H2 predicts that internal leadership positively moderates the relationship between board interlock network centrality and digital innovation. However, as shown in Model 3, the interaction between interlock centrality and internal leadership negatively affects digital innovation ($p < 0.01$), and thus H2 is not supported. H3 states intra-industry external leadership diminishes the positive relationship between interlock centrality and digital innovation. Model 3 shows intra-industry external leadership negatively moderates the main effect ($p < 0.01$), thus providing strong support for H3. H4 and H5 predict, respectively, that internal IT leadership and IT CEO positively moderates the relationship between interlock centrality and digital innovation. As shown in model 3, the interaction between interlock centrality and internal IT leadership positively affects digital innovation ($p < 0.01$), thus supporting H3. We found IT CEO does not significantly moderate the relationship between interlock network centrality and digital innovation, thus suggesting that H4 is not supported.

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Table 2 Descriptive Statistics and Correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Digital Innovation	1													
2. Interlock Centrality	0.14	1												
3. Internal Leadership	-0.08	-0.13	1											
4. Intra-industry External Leadership	-0.01	0.32	-0.12	1										
5. Internal IT Leadership	-0.00	0.04	0.30	-0.04	1									
6. ITCEO	-0.01	-0.01	0.02	-0.00	0.06	1								
7. Average Board Age	0.02	-0.02	-0.13	0.02	-0.08	-0.00	1							
8. Board Size	0.10	0.19	-0.28	-0.04	-0.04	0.01	0.02	1						
9. CEO duality	-0.03	-0.12	0.11	-0.04	0.12	-0.06	0.01	-0.06	1					
10. Firm Age	0.21	0.01	-0.06	-0.08	-0.07	-0.02	0.23	0.16	-0.02	1				
11. Firm Size	0.20	0.08	-0.10	-0.10	-0.04	-0.01	0.08	0.24	0.06	0.20	1			
12. R&D Expense	0.58	0.17	-0.09	-0.09	-0.02	0.07	0.03	0.22	-0.07	0.27	0.40	1		
13. Market-to-Book Ratio	0.04	-0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.02	0.05	0.06	1	
14. Current Ratio	-0.03	-0.02	0.05	0.05	0.07	0.04	0.11	-0.13	0.03	-0.06	-0.13	-0.06	0.01	1
Mean	8.43	0.02	0.18	0.06	0.01	0.05	58.55	6.57	0.37	13.51	8.05	185.90	196.70	2.76
Standard Deviation	55.21	0.04	0.14	0.14	0.03	0.21	5.33	2.34	0.48	10.45	25.01	611.20	1519.62	2.57
Min	0.00	0.00	0.00	0.00	0.00	0.00	37.67	1.00	0.00	0.00	0.00	0.00	-647.11	0.00
Max	1400.00	0.41	1.00	1.00	0.33	1.00	82.00	17.00	1.00	77.00	288.00	10611.00	121.43	30.673

Table 3 Regression Results

	Model 1	Model 2	Model3
Average Board Age	0.007	0.008	0.014
	(0.609)	(0.530)	(0.272)
Board Size	0.110 ***	0.069 *	0.069 *
	(0.000)	(0.027)	(0.027)

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CEO duality	0.190	0.191	0.235
	(0.117)	(0.113)	(0.051)
Firm Age	0.005	0.009	0.007
	(0.428)	(0.144)	(0.216)
Firm Size	0.011 *	0.009	0.011*
	(0.024)	(0.065)	(0.023)
R&D Expense	0.002 ***	0.002 ***	0.002 ***
	(0.000)	(0.000)	(0.000)
Market-to-Book Ratio	0.000	0.000	0.000
	(0.059)	(0.279)	(0.402)
Current Ratio	0.059 *	0.111 ***	0.118 ***
	(0.011)	(0.000)	(0.000)
Interlock Centrality		6.802 ***	22.577 ***
		(0.000)	(0.000)
INLSP		-2.21 ***	-0.896
		(0.000)	(0.201)
INEXLSP		1.944 ***	3.252 ***
		(0.000)	(0.000)
INITLSP		4.512 *	2.844
		(0.010)	(0.135)
ITCEO		0.167	0.351
		(0.586)	(0.329)
Interlock Centrality x INLSP			-87.959 ***
			(0.000)
Interlock Centrality x			-24.838 ***

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INEXLSP			(0.000)
Interlock Centrality x INITLSP			107.61 ** (0.003)
Interlock Centrality x ITCEO			-7.799 (0.348)
Observations	1324	1324	1324
2 x log-likelihood	-5325.005	-5257.496	-5240.835

Year and industry dummy variables are included; *p < 0.05, **p < 0.01, ***p < 0.001

6 Discussion

In this research, we propose that interlock network centrality has a positive impact on digital innovation. Our analysis of eigenvector centrality of the ICT industry interlock network provided support to the relationship between interlock network centrality and digital innovation. Based on the MOA model, we also propose that the relationship will be stronger when board of directors are motivated and have more abilities. We found that the external leadership on the board within the same industry and internal IT leadership positively moderate the relationship between interlock network centrality and digital innovation.

However, we found that internal leadership (i.e., the proposition of internal directors) showed a negative moderating effect on the relationship between interlock

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network centrality and digital innovation, opposing H2. One possible reason is that, in contrast to the ability offered by internal board members, groupthink and myopia imply more threats to boards. When high internal leadership is on a board, the board members become excessively close-knit. As a result of internal group pressure, the board of directors becomes impatient with appraising alternative strategies, which obstacles the development of digital innovation (Eaton, 2001). Therefore, internal leadership negatively moderates the relationship between interlock network centrality and digital innovation.

Another interesting finding is that IT CEO shows no significant moderating effect on the relationship between interlock network centrality and digital innovation. One plausible reason is that CEOs may get enough skills when sitting in the position, so their functional background will not moderate the relationship between interlock network centrality and digital innovation. Anyone who becomes a CEO is likely to have certain expertise developed over a lifetime, enabling them to achieve their position (Gottesman & Morey, 2010). Consequently, the relationship between interlock network centrality and digital innovation will not be changed despite of CEO's educational background or experiences. We hope that future research will shed more light on the moderating effect of CEOs' functional backgrounds on digital innovation.

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6.1 Theoretical Contributions

This research's findings extend the literature on top-down influences from the firm's senior leadership on innovation. Prior studies have examined how CEOs and CIOs influence digital innovation(Chen et al., 2021; Choi et al., 2021; Li et al., 2021), but the effect of board of directors is unclear. We find a positive relationship between interlock network centrality and digital innovation. Moreover, our findings also highlight the IT leadership on a firm's board, adding to the body of knowledge on the role of internal directors, external directors within the same industry, and IT executives on the board. Finally, when findings in the management literature have suggested that board interlocks influence many strategic behaviors (Barroso-Castro et al., 2015; Stevenson & Radin, 2009; Wincent et al., 2010), the effect of board interlocks on digital innovation had not been examined in previous research. The finding in this article, the positive relationship between interlock network centrality and digital innovation, extends the interlock literature in a novel way.

6.2 Managerial Contributions

This article's findings also generate useful implications for business practice. First, the results show that board interlocks work as bridges to valuable IT information, which is helpful for digital innovation. Managers may consider valuing

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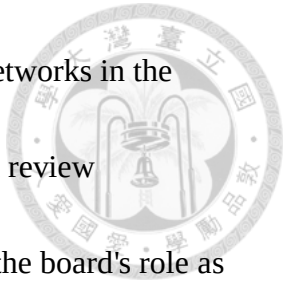

and formalizing the IT information benefits gained from interlock networks in the boardroom. For example, set up agenda about digital innovation and review information periodically in board meetings. Managers can leverage the board's role as a driver for improving information access to increase innovation outputs.

Another managerial implication is the moderating effect of the leadership on the board. We find internal IT executives strengthen the positive influence of board interlock network centrality and digital innovation. In contrast, the proportion of internal directors and the propotion of external intra-industry directors weaken the effect. Firms can use our insights to increase their digital innovation when considering board appointments.

7 Conclusion

7.1 Summary

How to effectively develop digital innovation has been an important issue for many firms. Drawing on social capital theory and the MOA model, we propose that firms are more likely to develop digital innovation when their board interlock network centrality is higher. Our findings also demonstrate that internal IT leadership on the board positively moderates the effect, whereas internal and intra-external leadership

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on the board negatively moderate the impact. Our results provide novel insight into the top-down influence of board interlock centrality on digital innovation.

7.2 Limitations and Future Works

We acknowledge a few shortcomings of our study, which provide opportunities for further research. First, we chose the ICT industry, in which IT information is emphasized, to avoid industry variation and conduct a clean empirical test. Further research can focus on other industries (e.g., biotechnology industries) to verify our findings and enhance the generalizability.

Second, we did not consider that intra-industry external board members might come from the same group of the focal firm. In that situation, the intra-industry external board members might be willing to share information. Future research can study deeper about the behavior of intra-industry external leadership on the board and its influence on digital innovation.

Third, we do not include extra-industry external leadership on the board in our research model. Intra-industry external leadership on the board was examined as a negative moderating effect between interlock network centrality and digital innovation in our research. On the other hand, extra-industry external board members might be more motivated and have ability to share IT information. Thus, extra-

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industry external leadership on the board is supposed to have a positive moderating effect, which may be examined in future research.

Fourth, we measured digital innovation based on the number of IT patents. While patents are generally considered as outcomes of innovation, they may not fully reflect a firm's digital innovation activities. Thus, future research can develop more refined measures of digital innovation.

Fifth, we use eigenvector centrality to measure interlock network centrality. Eigenvector centrality is one of methods to count centrality. Future research can use other kinds of measure to calculate centrality (e.g., degree centrality, betweenness centrality, and closeness centrality) to extend this research.

Sixth, we use interlock network as a proxy for board external social capital. We measured board external social capital by counting the interlock network centrality since interlock network is widely considered as a appropriate proxy of board external social capital. However, other social capital, such as friendship or other private relationships, also involves knowledge transfer and can bring information benefits to digital innovation. Therefore, further research can investigate different forms of social networks besides corporate relationships, obtaining a more highly comprehensive understanding of the influence of board external social capital on digital innovation.

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Finally, our study focuses on the influence of interlock network centrality on digital innovation. Future studies should also investigate how digital innovation enhances firm performance and how interlock network centrality influences the performance effect of digital innovation.

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Appendix

The interlock networks of firms in the ICT industry from 2009 to 2013

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