Accelerating Innovation Efficiency through Agile Leadership: The CEO Network Effects in China

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ABSTRACT

Digitalization as a business enabler has speeded and scaled innovation in many firms. As the corporate leader, the CEO facilitates strategic agility and enhances network effects to create value. This study uses innovation efficiency as the proxy of digitalization to examine the contribution of the CEO networks to firm-level innovation efficiency in Chinese listed firms. Using 13,516 firm-year observations in Chinese listed high-tech firms between 2007 and 2017, we apply a frontier analysis approach (e.g., DEA and SFA) and measure innovation efficiency based on the scale ratio of innovation output (i.e., patent counts) and input (R&D investment and R&D personnel). First, we find that innovation is more efficient when CEO has more outside directorships. Second, a significant and positive relationship exists between a well-connected CEO and innovation efficiency when the newly appointed CEO has larger networks than the predecessor. Third, the positive relationship between a well-connected CEO and innovation efficiency disappears when the number of outside directorships is above the yearly median level. This empirical study provides evidence for the network effects of a CEO for improving innovation efficiency. The findings emphasize the contingent value of the CEO's external social capital on agility, especially the multiple directorships in a transitional economy.

Keywords: Social Capital; CEO networks; CEO Transition; Agile Leadership; Digitalization; Innovation Efficiency.

1. INTRODUCTION

The ability of corporate leaders to navigate change has never been more crucial than in most recent years due to 'Black swan' events, such as Brexit and COVID-19. Whether a firm adapts to the challenges and opportunities ahead will depend largely on how agile the leaders are. On the other hand, digital architecture is designed to drive cross virtual collaborations and innovation. Agile leadership and digitalization implementation are two key factors of corporate success (Bushuyeva et al., 2019; Parker et al., 2015). However, empirical studies on the relationship between leader agility and corporate digitalization remain limited because of the lack of ideal proxies to measure these two variables numerically. Our study focuses on this issue and aims to fill this gap by proposing two possible proxies.

In the enterprise context, digitization involves the process of transforming assets from analog forms, such as paper-based, to digital forms. Digitalization helps firms increase speed, enhance efficiency and accelerate the pace of competition (Škare and Soriano, 2021). A digitalized firm converts invention ideas into products faster and consumes fewer resources than a non-digitalized firm (Aklamanu et al., 2016). All firms in competitive environments tend to digitalize their operation to improve operational efficiency. The more digitalized a firm is, the more efficient it can become. In this paper, we determine innovation efficiency as a scale ratio of innovation output (i.e., patent counts) and input (R&D investment and R&D personnel) (Wang et al., 2016). Previous literature has found that computerization and programming tend to increase patent production and replace manpower reliance (Miceli et al., 2021). As such, we use innovation efficiency as a proxy for digitalization.

According to the social capital and agility literature (Aklamanu et al., 2016; Braun et al., 2019; Cho et al., 2012; Doz, 2020; Ferraris et al., 2021; Mazzola et al., 2016), network effects (e.g., outside directorships) enable firms to be more agile, gain access to critical resources, legitimacy, and strategic information. With classic strategies being upended under the constant threat from new technologies and business disruption (e.g., caused by the COVID-19, Brexit, and the US-China trade war) occurring, innovation formulation and implementation have become imperative for most leaders (e.g., CEO) (Ferraris et al., 2021). Our study thus proposes that a well-connected CEO is an agile leader. As such, we use the number of CEO interlocking firms as a proxy for leadership agility.

We select China as our research background because China is arguably the most important industrial manufacturer globally. It sells more manufacturing products and services than any other country and has built up digital technologies in a highly pragmatic way. China has devoted considerable effort to technological innovation upgrades following the national plan. For example, the country spent more than $378 billion on research and development in 2020 alone, with a 10 percent increase compared to 2019 (Shead, 2021). This amount represented a level of innovation investment second only to the United States. However, innovation is often associated with risk. It requires agility (Lee and Yang, 2014) and is seen as costly, time-consuming, and uncertain (see Cao et al., 2015; Lee et al., 2020; Sariol and Abebe, 2017; Zhang et al., 2014a). Throwing money into innovative projects without considering their relative efficiencies may cause misuse of resources and drop organizational profitability. In order to address this concern, improving innovation efficiency is of considerable significance for enhancing the comprehensive strength and international competitiveness of companies.

Agility and speed of possessing digital information have become critical to foresighted emerging threats and seize new market opportunities before their rivals even notice them. This

study is motivated by the fact that digitalization as a business enabler has speeded and scaled innovation in many firms around the Asian region, particularly in China. With teams working remotely during the COVID-19 lockdown, many high-tech industries have shifted to agile working patterns and have embraced the digitization process. While digitalization accelerates the processes of innovation, the CEO, as the corporate leader, is there to set the stage for a learning process that facilitates strategic agility, adaptability, and flexibility (Ferraris et al., 2021; Vecchiato, 2015). Besides, the CEO also works with executives and business partners from external firms. The paper takes a stand on the empirical study that intends to provide evidence for the network effects of a CEO for improving innovation efficiency. The study focuses on how agility and digitalization enhance the contingent value of the CEO's external social capital (i.e., the number of outside directorships) without compromising innovation efficiency in a transitional economy. We, therefore, have raised three research questions:

1. What are the effects of agility on digitalization?
2. What are the effects of CEO transition on digitalization?
3. What is the possible relationship between digitalization and CEO network size?

While using a sample of the panel data set containing 13,516 firm-year observations in Chinese listed firms between 2007 and 2017, our empirical results show that if a CEO holds outside directorships, the firm tends to have higher innovation efficiency than its counterparts. Besides, a positive relationship is found between a well-connected CEO and innovation efficiency when the successor has more outside directorships than the predecessor. Moreover, the positive effects of a well-connected CEO on innovation efficiency will become non-significant after reaching a certain optimum level. Thus, our study supports the theory of social capital and suggests that the value of CEO networks could reinforce the positive effects on innovation efficiency in China.

This study proceeds as follows. After the introduction, there is a conceptual framework and research background section. A literature review on agility, CEO networks and innovation efficiency in a Chinese context is conducted, followed by the sample composition and methodology. The empirical results for this study are subsequently reported, addressing the network effects of CEO on innovation efficiency.

2. CONCEPTUAL FRAMEWORK AND RESEARCH BACKGROUND

A framework is designed to map and explore means of building the relationship between a leader's agile network effects and digitalization in the organization. The paper will identify how the number of CEO outside directorships affects innovation efficiency, even when other firm-level attributes are controlled in a Chinese context. Following Tsai and Ghoshal (1998), this study defines network effects as the reciprocated information inherent in social networks that connect between individuals or groups. There are two channels of network effects in the social capital literature, one is information transmission (Cho et al., 2012; Degbey et al., 2021; Hughes et al., 2020; Lee and Yang, 2014), and the other channel is the power status and influence (Griffin et al., 2021; Kaczmarek et al., 2014; Mazzola et al., 2016; Mizruchi, 1996). Studies (Braun et al., 2019; Srinivasan et al., 2018) have contended that the occurrence of the network benefits and risks arise from these two channels empirically and theoretically.

Several studies support the idea of information transmission social capital (e.g., Avina-Vazquez and Uddin, 2016; Engelberg et al., 2012; Aklamanu et al., 2016; Li et al., 2013; Srinivasan et al., 2018). These studies evidence that social capital opens up new avenues to help build an agile firm via social networks for less-costly knowledge-information circulation, cost of external financing reduction, managerial trust enhancement and quick response to the

dynamic and uncertain business environment (Lee and Yang, 2014; Vecchiato, 2015). Similar benefits of CEO networks are documented in Griffin et al. (2021), Engelberg et al. (2012), Haynes and Hillman (2010). Especially informal networks with stakeholders, lenders and borrowers transmitting information could save on tax, lower interest rates, obtain larger loans, and build stable collaboration platforms. Innovation is always associated with change and risk (Zhang et al., 2014a) and creating an environment in which agile flourishes may churn out faster and more successful innovations (Doz, 2020; e Cunha et al., 2020). In the battle for innovation, the information-based benefit of CEO networks, thus, is likely to create the best possible pathway for channeling resources towards innovation to blossom. The social capital theory assumes that firms are not restricted in their own resources but can go beyond what they have by exchanging and gaining valuable resources through inter-personal or inter-firm networks (Mazzola et al., 2016) to cooperate, compete and survive (Griffin et al., 2021; Salancik and Pfeffer, 1978; Teece et al., 2016; Trost, 2020). Wang et al. (2013) stress that agile innovation efficiency requires a cognitive orientation, resources, and social capital from the leader. The agility and cognitive orientation help explain why CEOs may rationally improve innovation efficiency to lower shareholders' and creditors' adverse perception of high variance in a firm's economic activities (e.g., R&D spending and patents, Lin et al., 2011). However, the benefits of the information transmission channel go beyond access to what we have discussed. *Guanxi* is one of the traditions in the Chinese business environment (Zhang et al. 2014b). Li et al. (2013) point out that CEOs could also use their connections and *guanxi* networks as a signaling device to influence the quality of strategic initiatives and reduce asymmetric information (Khan and Mauldin, 2020; Sariol and Abebe, 2017). Additional benefits include reducing bureaucratic processes and gaining trust and credibility with stakeholders to support innovative endeavors (Dalziel et al., 2011; Jagtap and Duong, 2019). Furthermore, CEO with large networks is under more public monitoring and at a higher risk of a damaging reputation for detected misconduct. Thus, the innovation cemented CEO networks that might have drifted to the agility competition (Doz, 2020).

Additionally, when CEOs enjoy the benefits of their outside directorships and start expanding their networks, Griffin et al. (2021) find that CEOs are under high stress to provide substantial output and achieve marketplace anticipation with their multiple directorships. Therefore, with high stress to improve the output and greater reputation concerns, the over-boarding CEOs may overweigh the benefits of dynamic and varied experience, thus, restricting the agility in action and diminishing innovation efficiency.

For the power status and influence channel, we follow Griffin et al. (2021) and further empower the CEO networks in two ways to enhance innovation efficiency. First, this channel emphasizes the power and influence of CEOs and elicit support from the board and top management team. In China, CEOs' power is more salient than CEOs of similar company sizes in other developing countries (Wei and Ling, 2015). Although the Chinese transition from a strategic to a marketplace economy has been taking place for decades, many firms still expect CEOs to be at the helm of the firm and see the directors as a symbol of regulation compliance (Jiang and Kim, 2015). While other board members and top executive management team members participate in decision-making at the strategic level, CEOs are expected to build an environment for agility (Lee and Yang, 2014) in which innovation can flourish and act as a cheerleader (Berger et al., 2016). Some studies (e.g., Wei and Ling, 2015) argue the monitoring function of the board members and the supervisory board is constrained in Chinese firms due to weak independence. For example, in big state-owned enterprises, board members are nominated and appointed by government departments, who often follow the socialist agenda and prefer members to work in senior positions (e.g., the CEO) (Lin et al., 2014). The high ratio of dual CEOs (we reported 38% of firms are led by a dual chairperson-CEO leadership) and a weak monitoring board helps reinforce the CEO's power and prominent structural

position in the organization's upper echelons (Cao et al. 2017). As a result, it gives the CEO essential resources to establish a fiscal and innovation efficiency responsibility structure that he/she could directly oversee.

The second way of the power status and influence channel is to reduce career concerns and provide labor market insurance for CEOs if they receive penalties for poor performance. The CEO's personal links to government, shareholders, other firms, and economic agents create new information-sharing channels and obtain valuable resources for the connected individuals. Studies in the social capital literature find that career concerns cause executives to have low-risk tolerance and forgo innovative projects (Jensen and Meckling, 1976; Griffin et al., 2021), meaning that a large network size relates to risk-taking behaviors (Dbouk et al., 2020). However, such concerns can be reduced if social capital could minimize information asymmetry (Ferraris et al., 2021; Hughes et al., 2020). Dbouk et al. (2020) and Hoi et al. (2019) find that CEO with strong social networks (e.g., outside directorships) is more comfortable with making the jump from one to another company even when there are not many employment options in the labor market. The network effects also motivate peer interaction. Studies (Avina-Vazquez and Uddin, 2016; Fracassi 2016) find that as the information travels through social networks, it affects the CEO's decision making, applying digital agility and products commercialization (e Cunha et al., 2020; Shams et al., 2021; Srinivasan et al. 2018; Wang et al., 2016). Interestingly, the connected individuals tend to have similar capital investments, which means they are likely to be risk-taking as they share information and risk in society. Given the unique features of the Chinese institutional setting, the responsibilities of the CEO are highly likely to impact strategic direction significantly, for example, by spurring innovation-related activities and new technologies and affecting the formulation and implementation of their innovation investment (e.g., patents). Such an impact will be leveraged by the CEO's social capital.

China has the most significant potential market of innovation users due to its vast population. Identifying factors that affect innovation efficiency is critical for a firm to be agile to face global competition and to remain in a leading position in the market. In China, most resources (e.g., finance and advanced technologies) are controlled by central banks and other large firms (Gao, 2008). Assessing such resources led to complex dependent relationships among firms in China. In this institutional environment, the incentives are strong for firms or individuals to form interlocking ties between firms to assess the required resources to leverage a focal firm's resource restriction and maximize agility (Chan et al., 2019; Shams et al., 2021; Wang et al., 2013). Following this logic, this study focuses on the contribution of a CEO's outside directorships in a Chinese context. In sum, this study argues that a better-connected CEO signals to the market that firms with this type of CEO can make rapid decisions and operate within a competitive environment agilely and access resources externally, thus enhancing innovation efficiency.

The overall conceptual framework is developed to guide the discussion and summarized in Figure 1.
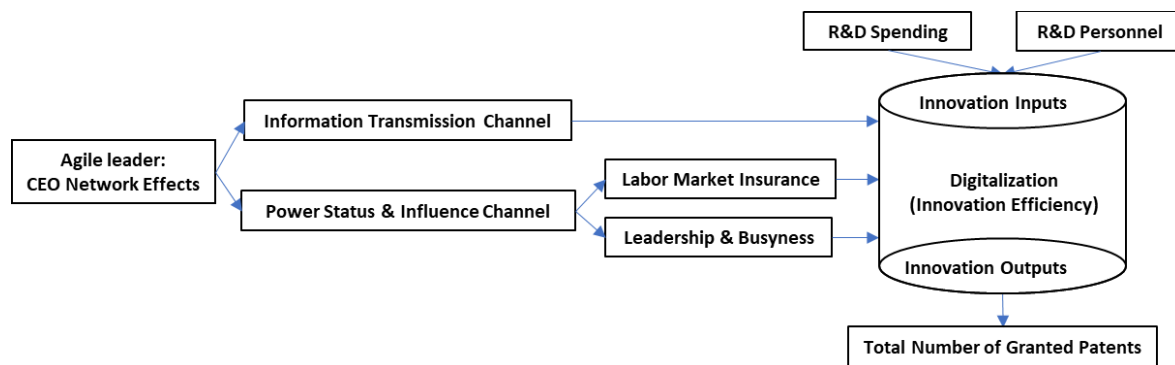
Figure 1: A Conceptual framework of CEO Network Effects

3. LITERATURE REVIEW AND HYPOTHESES

3.1 CEO Outside Directorships and Innovation Efficiency

Vecchiato (2015) comments that agility is the capability of an organization to adapt, renew itself, and thrive in a rapidly ambiguous, changing, and raging environment. Teece et al. (2016) see organizational agility as the ability of an organization to adapt to changes in the marketplace to gain competitiveness quickly. However, many firms struggle with adopting new technologies during the COVID-19 (Chan et al., 2019; Noyes, 2020). Therefore, agility is essential in responding the digital disruption. In fact, the desire to be agile is progressively unrelenting for companies, particularly those functioning in wide-ranging culturally host nations (Martínez-Climent et al., 2019; Shams et al., 2021; Trost, 2020). According to Shams et al. (2021), multinational enterprises (MNEs) have advocated that digitalization encourages strategic agility and reduces the risk of falling into inelasticity traps that may result in business failure. From a diverse standpoint, studies (e.g., Akhtar et al., 2018; Chan et al., 2019; Scuotto et al., 2017) propose that firms take advantage of digital technologies and create higher value when agile firms' abilities are continuously developed and employed. This takes place, for instance, when they are capable of foreseeing how these new digital tools would take in the effect of the contemporary business practices, products and business models (Jagtap & Duong, 2019; Scuotto et al., 2017; Vecchiato, 2015).

At an individual level, the existence of a CEO in another firm's board provides the potential for mutual CEO intertwine, strengthening strategic links between two or more companies (Helmers et al., 2017). According to social capital theory, there are many benefits to having a CEO who also serves on multiple directorships. For example, CEOs with external business ties know whether the practices and relevant policies are being followed by other subsidiaries and can thus avoid discrepancies (Cao et al., 2017). Custodió and Metzger (2014) find that a CEO with a finance career background in the Standard and Poor's 1,500 firms is more actively managing focal firms' financial policies and is highly likely to raise external funds even when the tight credit situation occurs. They also find that mature firms are more willing to hire financial expert CEOs. In a recent study, Škare and Soriano (2021) find that if family firms in the EU want to increase agility, they must invest in human capital. Ferraris et al. (2021) find a positive relationship between the tenure of subsidiary CEOs in India along with their social capital and multinational enterprise strategic agility. Following this logic, the CEO might work more productively with an agility mindset in the digital era, thus further strengthening his/her social networks in the society (e.g., directorships in other companies) to achieve a greater outcome (e.g., innovation efficiency).

When digitalization is powered up by cutting-edge technologies and data-driven insights, it encourages agility. This is because it improves the responsiveness and flexibility of firms, such as allowing efficiency, identifying changes early (Vecchiato, 2020) and coordinating connecting with business partners and processes effectively (Miceli et al., 2021; Škare and

Soriano, 2021). According to Miceli et al. (2021), both digitalization and agility are prospective through various practices (e.g., specific investments in intangible assets, guiding and inspiring between firms). All these practices improve the active stance and agile working in addition to the resilience of the business (Miceli et al., 2021; Škare and Soriano, 2021). Furthermore, digitalization improves the sustainability of businesses, and the use of advanced technologies can increase productivity through the integration of information technology, production and supply chain (Shams et al., 2021).

The uncertainty of the market demand and the timing of new product launches make innovation particularly daunting in a business environment. Therefore, it is important for CEOs to embrace agility (Dabić et al., 2021), learn new skills from holding outside directorships and apply this knowledge to the focal firms (Bhandari et al., 2018; Wei and Ling et al., 2015). For example, the CEO can initiate a chain that sparks agile innovation by having innovation labs that let selected R&D personnel vet their innovative ideas against the firm's required capital and strategic direction. Moreover, serving specific industries, such as banks and high-tech or MNEs, enhances a CEO's awareness of the trends in micro-and macro-economic factors and levels up a CEO's agile mindset (Custodió and Metzger, 2014; Hung et al., 2017; Martínez-Climent et al., 2019; Vecchiato, 2015). Doz (2020) finds that an increasing number of firms need to attain strategic agility, which results from strategic sensitivity, leadership unity, and resource fluidity. However, those firms face a lot of competition and diversity in addition to the domineering of key strategic redirections (e.g., toward Asian or other developing marketplaces) as sources of new competencies, knowledge, or new business models in the wake of digital disruption or digitalization. Further, Doz (2020) argues that senior executives' (e.g., CEO) social capital and professional interaction with outsiders contribute to gaining strategic sensitivity and competitive advantages. Also, the assessment of resources made by holding one or more outside directorships helps CEOs stimulate ideas of new technologies and productions, then execute the focal firms' growth strategies (e.g., innovation). Take the emerging online-to-offline (O2O) platforms in China as an example - they set a new norm, such as shopping experiences, media care and other professional consultations in a post-COVID-19 world. Traditional businesses (e.g., banks, hotels, restaurants and boutiques) that shy away from offering digital services are increasingly connecting with O2O platforms and trying to be the survival of the fittest. Hence, the hypothesis can be stated as follows:

H1: There is a positive relationship between agility and digitalization.

3.2   CEO Transition

According to social capital theory, the presence of a well-connected CEO (i.e., he/she sits on multiple external boards) in a firm reflects the strong market connections. Bhandari et al. (2018) specify that CEOs who have larger external connections are related to higher audit quality and provide economic benefits (Dabić et al., 2021) and intellectual agility (Doz, 2020) to focal firms. An invitation or appointment to act as a board member in an external firm acknowledges the CEO's expertise that, to some extent, enhances the social status in the market (Griffin et al., 2021; Boivie et al. 2016) and the influence of the CEO with the focal firm (Khan and Mauldin, 2020). While gaining experiences, reputation and reducing risks of opportunistic behaviors of sitting on external boards, the CEO has the potential to use these resources to accelerate and update focal firm's technologies, digital transformation, research and industrial commercialization (Doz, 2020), thus creating an agile environment and enhancing innovation efficiency (Cao et al. 2015; Dbouk et a. 2020; Lee et al. 2020; Sariol and Abebe, 2017), capital management (Bhandari et al. 2018; Custódio and Metzger, 2014) and overall efficiency of the firm. Therefore, there is a higher possibility of building a culture of innovation when a well-connected CEO can embed successful and agile innovation strategies and learn failure cases

from other connected firms. Similar to Doz (2020), Debellis et al. (2020) also have drawn on three key capabilities that enable strategic agility (i.e., leadership unity, strategic sensitivity, and resource fluidity). They have developed a hypothetical framework that unravels this inconsistency. Particularly, they argue that senior management who is resourceful (e.g., professional interactions) with a strong passion for creating value through foresight would enhance family firms' strategic sensitivity (e.g., managing threats and seizing opportunities) and be more innovative (Debellis et al. 2020). Overall, when a firm decides to appoint a new CEO, it is reasonable to consider a person with more outside directorships than the current or previous CEO. The following second hypothesis is formulated:

H2: There is a positive relationship between digitalization and agility when the incoming CEO has more outside directorships than the predecessor.

3.3   CEO Busyness

According to the power status and influence channel of social capital, some CEOs may be keen to expand his/her network through multiple appointments due to the potential benefit of individual career development and social status in society. On the other hand, many firms restrict or prohibit the CEO's outside directorship appointments because it requires a time commitment and detracts from the CEO's agility to work effectively on the focal firm (Harymawan et al., 2019; Kahan and Mauldin, 2020). For example, in an American context, Kahan and Mauldin (2020) find that 24% of CEOs have outside directorships, but little evidence showed that these network ties help CEOs transfer knowledge and enable the CEOs to improve practices in their focal firms. In an Indonesian context, Harymawan et al. (2019) report a negative CEO busyness and firm performance relationship, and their results suggest that it is not wise for a firm to have a CEO who holds two or more outside directorships. According to this busyness argument, Spencer Stuart (2019) reports that 77% of American listed firms set restrictions on directors and executive appointments on outside directorships in 2019. From a human resource management perspective, e Cunha et al. (2020) state that executive attention is a significant but limited resource to develop strategic agility among MNEs because strategic agility requires a timely, responsive and powerful action model to support it (Martínez-Climent et al., 2019). Interestingly, Doz (2020) demonstrates that senior executives consider that their time in practice (5-10%) should be increased to 40-50%. The participants have provided feedback that learning how to use it effectively for external-strategic networks is more important than freeing up their time. In China, the newly revised version of Guidelines for Independent Directors of Listed Companies in 2020 (Article 6, No. 48) clearly stated that, in principle, an independent director should not hold more than five outside directorships to ensure time commitment and obligate responsibilities effectively. To investigate the drivers for concern over a CEO's multiple outside directorships, we propose:

H3: There is a negative effect of CEO network size on digitalization after reaching an optimal level.

4.   DATA AND METHODOLOGY

This study uses year-end financial and board data collected from the *CSMAR* and *SIPO* databases. We have restricted the data for this research to eleven years (2007-2017) because of the limitation of R&D data in *CSMAR* and *SIPO*. The sample of firms was drawn from the Shanghai Stock Exchange (SHSE) and Shenzhen Stock Exchange (SZSE). After removing observations without R&D investment data and granted patents, such as R&D investment,

R&D personnel, and R&D outputs, it yields a total of 13,516 firm-year observations. We winsorize all continuous variables at 1% and 99% levels. Our sampling strategy is consistent with existing studies (e.g., Sial et al., 2018).

We use the DEA and SFA procedures as our main efficiency measurement method to reconcile the measurement indicators and measure the level of innovation productivity. Indicators of innovation efficiency measurement are determined by identifying and integrating innovation-related literature, characteristics, and activities (Duran et al., 2016). This research used two variables to measure innovation input. The first is R&D investment, including typical resources and funds that initiate, support and maintain innovation activities (Classen et al., 2014). The second input is the number of R&D personnel. Recruiting the right number of researchers with the right skills (i.e., using emerging technologies and knowledge of present research) in a firm's R&D department is critical for motivating and helping firms formulate and implement innovation activities. This group of researchers is directly involved in productivity and value-creation activities (Wang et al., 2016).

The output of innovation is identified as technical knowledge, mainly those codified in patents. Thus, patents are an essential variable for innovation. As in several existing studies (Zhang et al., 2014a; Wang et al., 2016), the patent is considered the primary innovation output in this study. It is worth mentioning that not all R&D investment necessarily leads to patents, and not all innovation products or activities can be patented. Nevertheless, the number of patent applications is one of the most frequently used measures of innovation output. Wang et al. (2013) view the number of granted patents as an indicator of organizational knowledge, potentially influencing organizational financial performance. We choose the number of granted patents as an innovation output in this study for these reasons.

Data Envelopment Analysis (DEA) procedure is a widely used non-parametric technique to estimate innovation efficiency (Charnes et al. 1978). DEA is selected in this study because it is more sensitive to sample heterogeneity (Fiorentino et al., 2006). This sample heterogeneity has generally been found using samples from the Chinese manufacturing sector (Abraham and Konings, 2010). Another advantage of using DEA is that it only requires input (i.e., R&D personnel and R&D investment) and output (i.e., granted patent counts) quantities. According to Hjalmarsson and Veiderpass (1992), innovation effectiveness is normally measured concerning the utmost perceived innovation performance instead of an average score.

Charnes et al. (1978) introduced the Model (1) to measure innovation efficiency:

$$TE = \min_{\theta,\tau} \theta$$
$$Y\tau \geq y_k$$
$$s.t \; X\tau \leq \theta x_k$$
$$\tau \geq 0 \qquad\qquad\qquad (1)$$

We follow this model to measure efficiency, create a score, and rank our sample companies based on the scores. The innovation scores range from 0 to 100. To estimate the DEA innovation score, we use R&D investment and the number of R&D workforces as input values, and the output variable is the number of granted patents.

Stochastic Frontier Analysis (SFA) is another analysis to calculate the efficiency score (Aigner et al. 1977). The SFA has been used substantially in innovation and production literature (Huang et al., 2016; Wang et al., 2016). Different from DEA, the SFA is a non-parametric method to estimate the effectiveness scores. The estimated innovation frontier could enable us to approximate the input and output values in the calculation. Therefore, the SFA is used as a robustness analysis to find out whether the outcomes are consistent with the results of DEA.

The CEO network size is measured as the number of outside directorships that the CEO holds in other firms (Harymawan et al., 2019). Several firm-level control variables are also

included. They are firm age, leverage, ROA, Tobin's Q, and total assets (Khan and Mauldin, 2020, Zhang et al., 2014a).

Insert Table 1 & 2 about here

Table 1 displays definitions of all variables. Table 2 shows statistic descriptions of all variables. As shown in Table 2, the efficiency means are 31.3% in DEA and 26.4% in SFA. On average, firms in this study tend to invest $169 million and recruit 610 staff to work in R&D-related activities and have an output of about 167 granted patents. The results consistent with Wang et al. (2016) imply that the sample firms have not been performing at an optimal level of efficiency. For firm-level control variables, sample firms' age is about 15 years, meaning the sample firms are relatively new to the stock market. The leverage is 36.9% with 3.3% ROA, on average. Tobin's Q is 53.4% on average. In the CEO network size variable, the mean value of additional board positions that a CEO hold is 2, which is consistent with Rathod (2018).

Insert Table 3 about here

Table 3 presents the results of the Pearson correlation matrixes of all variables. One point is noteworthy, DEA is highly correlated with SFA (0.91), but these two dependent variables are in a separate regression model. Otherwise, the relatively low absolute values (less than 0.8 thresholds) of Pearson correlation coefficients indicate no multicollinearity issue (Hair et al., 2017).

After a Hausman test, a board data analysis fixed impacts regression is used to examine the three hypotheses. Additionally, a two-step SGMM (System Generalised Method of Moments) is used as a robustness test to control endogeneity and fix two econometric problems for the dynamic panel models (Mangena et al., 2012; Wintoki et al., 2012). The first problem is causality. The influence between the independent (the CEO network size and control values) as well as dependent values (innovation efficiency) in the regression model (1) might occur in both directions (Arellano and Bover, 1995), such as from the CEO network size and control variables to innovation efficiency and *vice versa*. Also, there could be a relationship between the error term as well as independent variables. Second, the fixed effects problem. According to Blundell and Bond (1998), the time-invariant firm-level variables could be correlated with the independent variables. Using SGMM can produce less biased estimates and enhance the precision of the results. It also assumes there is no relationship between the error term and the instruments. Moreover, the importance of SGMM is that it includes the lagged levels and differences of variables as instruments simultaneously (Roodman, 2006; Wintoki et al., 2012). Several studies have used SGMM in corporate governance and innovation literature (Waweru et al., 2019).

In sum, we use both OLS and SGMM to examine our baseline model:

$$InnovationEfficiency_{i,t} = CEONetworkSize_{it} + ControlVariables_{it} + \varepsilon_{i,t} \qquad (2)$$

5.   RESULTS, DISCUSSION AND IMPLICATIONS
5.1 Results
We use the multiple regression analysis to test the network effects of CEOs' outside directorships, CEO transition and the diminishing effects on innovation. Results in Table 4

Column 1 show support for H1, confirming a positive and significant relationship between agility and digitalization ($\beta = 0.00121$, $p < 0.05$). This result may reflect that crucial external information and resources can be accessed if a CEO holds multiple directorships. More specifically, these CEOs could potentially replicate innovation activities or alternative sources of ideas across their connected firms (Doz, 2020). This finding is aligned with social capital theory and previous evidence (Han and Li, 2015; Sariol and Abebe, 2017). It has been particularly challenging for China in recent years due to the COVID-19 global crisis and the US-China trade war with growing technology protectionism and isolationism (Boylan et al. 2020). Our study shows that social networks seem important amongst the Chinese high-tech firms to learn the domestic and overseas experience of an innovation ecosystem and work coordinately to de-escalate the trade war and COVID-19 impacts.

To help us further understand a CEO's network effects on innovation efficiency, we use CEO transition as an event study to investigate the difference in innovation efficiency before and after the transition. In H2, we posit a positive relationship between digitalization and agility when the incoming CEO has more outside directorships than his/her predecessor. We separate the firms into two sub-groups (see Table 5), one sub-group with a new CEO having fewer outside directorships (87 observations) and the other sub-group with new CEO having more outside directorships than the predecessor (194 observations). The data one year before and one year after the CEO transition are used in the analysis. 281 transition events remained after excluding events with the same number of outside directorships before and after transitions and events with missing data before or after transitions.

Insert Table 4 about here

The DEA Column in Table 5 shows that when a new CEO has fewer outside directorships, the innovation efficiency score (0.3082) after the transition is lower than before the transition (0.3704). In contrast, when the incoming CEO has more outside directorships, the innovation efficiency score (0.3437) after the transition is higher than before the transition (0.2972). Therefore, H2 is supported. This event study provides us with another evidence that there is a positive relationship between agility and digitalization. Our results are consistent with Srinivasan et al. (2018), and we explain that the CEOs having multiple board appointments is vital for firms because of its network effects. In developing countries, such as China, governmental regulations, policies, and laws evolve (Zhang et al., 2014b), and concerns of risks and uncertainties in relation to the interpretation and application of these regulations, policies and laws (Laux and Stocken, 2018). Jia et al. (2012) specify that scholars in the management and organization literature use *guanxi* to build relationships with other firms and the concept of *guanxi* is China-specific. Therefore, we argue that firms will benefit from appointing a new CEO with more outside directorships than the predecessor because a well-connected COE can act as an information conduit between firms. The CEO could familiarize himself/herself with various policies and perhaps political processes and help the focal firm grow and expand in the long term.

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Insert Table 5 about here
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In H3, we hypothesize that there is a negative effect of CEO network size on digitalization after reaching an optimal level. Following Tosi et al. (1994), we first separate the sample firms into

large network size (7,702 observations) and small network size (5,814 observations) sub-groups using the annual median number of CEO outside directorships as a cut-off point (See Tables 6 and 7). The univariate analysis compares the key variables between the two sub-groups, and the results are recorded in Table 7. The results in Table 7 confirm that the efficiency scores (DEA and SFA) of the large network group are significantly larger than those of the small network group, supporting H3. We further conduct regression analysis on these two sub-group data (see results in Table 8). The regression coefficients for CEO outside directorships are significantly positive ($\beta = 0.0342$ for DEA and $\beta = 0.0575$ for SFA) in the small network size sub-group (in Columns 3 and 4) but are insignificant in the large network size sub-group (in Columns 1 and 2).

We added a square term of CEO network size to our baseline model (Table 4 Columns 1 and 2) and the regression results are recorded in Table 8 Columns 5 and 6. The negative coefficients on the square term ($\beta = 0.00004$ for DEA and $\beta = 0.0000631$ for SFA) indicate an inverted U-shape relationship between CEO network size and firm efficiency.

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Insert Table 6 about here
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5.2 Robustness Check

First, the SGMM approach is used to check the results of the correlation between innovation efficiency and CEO outside directorships. According to Wintoki et al. (2012), the Sargan-Hansen test and the Chi-Square test are carried out to assess the reliability of the estimates and ensure the results are free from methodological issues. As indicated in Table 4, the models of DEA and SFA under the SGMM column, the Sargan-Hansen tests generate p-values of 1 (Roodman, 2006), implying that the additional subset of instruments is not econometrically exogenous. Additionally, the SGMM column results are consistent with the Panel Data FE column, thus confirming that our results have persisted. Second, an alternate set of efficiency scores (i.e., SFA) is used, and the analyses again yield results similar to those using DEA efficiency scores (see Tables 4 and 7).

5.3 Discussion and implication

In many firms, digitization is driven by demands to counter rivals and foresee yet unidentified competitors. However, many firms struggle or fail to tackle digital disruption (Chan et al., 2019). Most of the time, the cause of the unsuccessfulness is that firms set unrealistic objectives or try to maintain a business strategy that is not flexible during uncertainty (e.g., COVID-19). Digitalization needs to be applied as an all-inclusive change plan to achieve a balance between sustaining constant business processes and innovation and preserving enough opportunity for strategic agility. In an extremely dynamic and volatile environment, increasing firm agility is an important success factor for businesses (e.g., high-tech firms, family firms, and MNEs). To better market new services or products in the marketplace, it is important to build an agile culture at both the firm and individual levels. It would help use simplified and efficient processes to increase innovation efficiency. Additionally, corporate leaders (e.g., CEOs) could inspire their workers to act and think in an even more innovative way and extend the individual scope for both private and public policymaking (Vecchiato, 2015). As Doz (2020) mentioned,

the CEO is more a facilitator to unite workers and business partners to maximize network effects.

Our results show that the CEO outside directorships positively impact firm efficiency when the CEO network size is below the annual median value. CEO outside directorships may be observed as a two-edged sword provided their learning advantages on the one hand and the prospective of disrupting CEOs from their focal firm's responsibilities on the other hand. Compared to other board members, CEOs are the most demanded leader because of their direct experience with strategic leadership. Therefore, there is a shift from reactive to creative and from traditional to agile approaches that give CEOs a competitive edge (Parker et al., 2015). Altogether, outside board experiences remain a valuable leadership instrument to prepare managers for CEO positions and keep their executive skills up-to-date.

The asymmetric effect between the large and small network size has prompted us to investigate further the possible nonlinear relationship between the CEO network size and the innovation efficiency. A positive relationship has been found in our study. Additionally, as discussed in the literature, digitalization allows strategically agile practices. Digitalization, such as big data analysis, could assist in predicting change. Because of its exceptional interconnectivity could simplify coordination and communication with multiple or even large groups of stakeholders (Jagtap and Duong, 2019). However, we should not ignore the possible negative effect regarding privacy concerns and, hence, conflict with societal sustainability (Miceli et al., 2021).

Our results also indicate that the network effects become weaker when the network size reaches an optimal point. The results are consistent with the social capital theory that when a CEO sits on more external boards, it eventually improves the firm's innovation efficiency using his/her network, agility, resources, or previous work experience. However, if the network size is too large, it tends to lower the efficiency of innovation when the busyness phenomenon occurs. In this case, according to Khan and Mauldin (2020), a busy CEO could potentially focus on personal benefits (e.g., reputations, social status, and personal career progression) from outside directorships rather than on contribution to the productivity of knowledge transfer to the focal firms (Boivie et al., 2016).

The control mechanisms in corporate governance and policymakers may view external board executive posts as a tool to advance managerial interests at the cost of stakeholder interests. However, our study argues that being agile could help CEOs learn how to use their time wisely and effectively. It would speed in responding to crises and uncertainties rather than focusing too much on solving day-to-day operational issues.

6. LIMITATIONS AND RECOMMENDATIONS

We identify some limitations that will provide future research opportunities. First, while investigating the benefits and risks of CEO network effects is undoubtedly valid, it is worth studying the disruption and changing environments. Both factors are due to the increased flexibility and mobility, unlocking more agile time for the CEO, other board members, or even the employees in general (Chaston and Sadler-Smith, 2012; Yang and Wang, 2014). Digital transformation is rising in firms at all levels to the challenges of COVID-19. We recommend board activities to embrace digitalization to maximize the wealth that firms derive from the board. Our result shows that in China, one CEO holds about two outside board positions averagely, not to mention the multiple directorships of other board members. This means that they are very busy people with rich experience and a high profile in society. Digital transformation with agile leadership could reduce reliance on time-consuming activities (e.g., admin work and traveling for business) by embracing agile working practices and achieving the balance between busyness and effectiveness (Doz, 2020; Lee and Yang, 2014). As a result, the inverse U-shape inflection point could be higher in the innovation efficiency score (see

Figure 2). For example, making information securely available online 24/7 indicates that the directors can access and review information without time limits and geographic restrictions. Additionally, directors can manage their time more effectively by concentrating on corporate governance and strategic insight that enhance high organizational performance to build an agile business through digital board solutions (Noyes, 2020; Rathod, 2018).

Second, future studies could adopt other measurements of CEO networks and investigate the relationship between CEO network effects, digitalization transformation, and innovation efficiency. Due to the unpredictable and competitive business environment, shareholders put heavy pressure on the board and push firms to be on top of digitalization. They expect positive results from their investment and a future-proof, forward-looking digital business. However, ZoBell (2018) reports that 70% of digital transformation investments failed to reach their goals. That is $900 billion out of $1.3 trillion misaligned tech investments and went to waste. To face this challenge, we recommend future studies to consider how CEOs could work with their networks and apply an agile approach to work efficiently and effectively, enabled by the right digital tools. This can then effectively use their time and maximize the network effects, in turn, pushing innovation efficiency from Inflection Point 1 line a to a new high (see Inflection Point 2, line b in Figure 2).
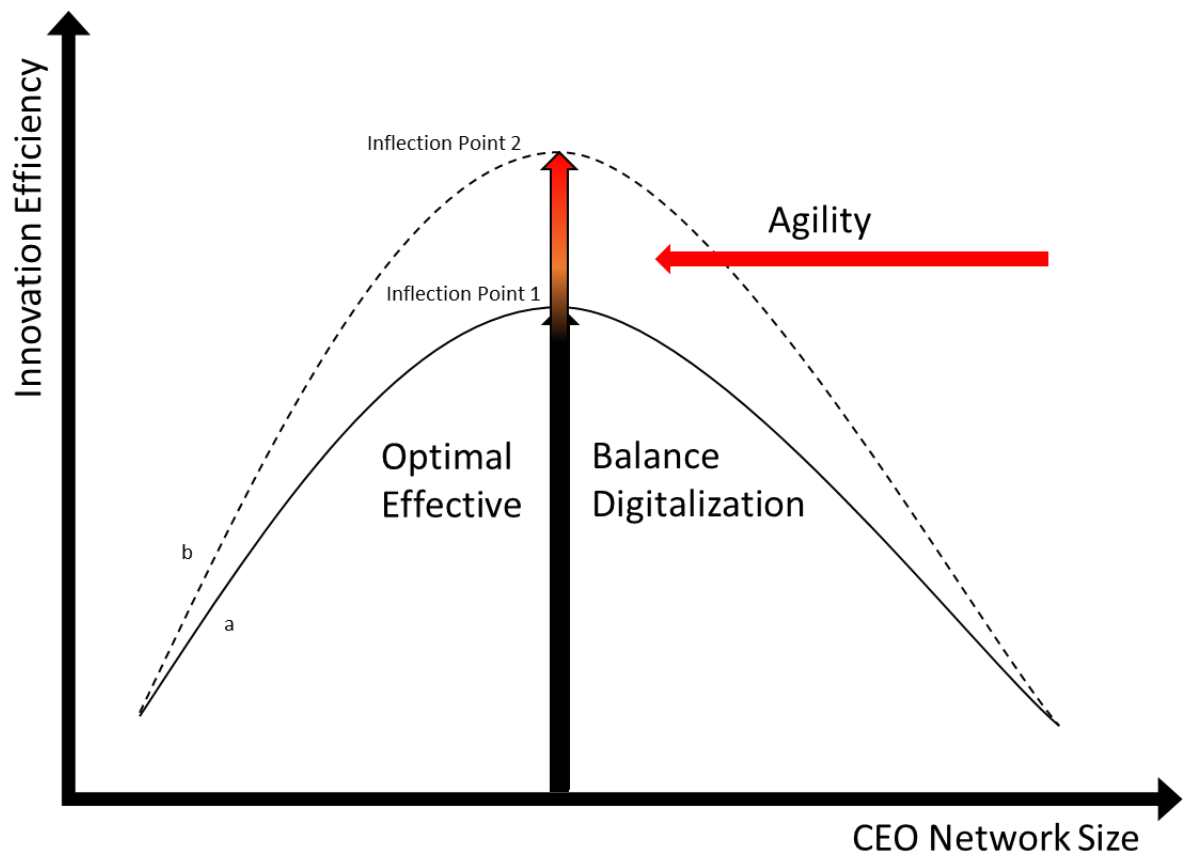

Figure 2 Accelerating Innovation Efficiency through Agility

7. CONCLUSION

A leader's agility has a substantial influence on firm digitalization. The CEO's network effects are an essential determinant in relation to our findings between agility and digitalization. Our empirical findings show that the number of CEO outside directorships positively affects

innovation efficiency, even when other company-level features are regulated in a Chinese context. We theorize that the positive network effects occur due to the information transmission and power status. Moreover, influence channels from an intensive CEO network allow the facilitation of digitalization to satisfy the interests of individuals and firms. Based on our empirical results, we assert that the benefits of appointing CEOs with multiple outside directorships can surpass the potential risks and uncertainty that come with digitalization. Doing so also helps innovative firms form agility and overcome project failures or overestimated R&D investment, in turn maximizing productivity. Well-connected CEOs send signals to potential investors that they can efficiently estimate R&D investment, manage researchers, and enhance the quality of innovation outputs (i.e., patents). We also find that a better-connected CEO may have fewer re-employment concerns in the labor market. Additionally, when the network size is too big to be handled, our results indicate a dark side of an over-boarding CEO regarding innovation efficiency. However, CEOs may flee before the dark side by embracing digitalization and agility.

Our empirical results present strong evidence for policymakers to implement and design towards industry or national digitalization. We also provide empirical evidence to support managers in maintaining a balance of their external networks to increase agility, in other words, enhancing innovation efficiency. To researchers, we are the first study using the CEO's network effects as another alternative to measure agility and provide an in-depth study. We build a starting point to investigate the linkage between agility and digitalization and use Chinese firms to illustrate our research contributions. Digitalization determinants demonstrated in the paper can eventually motivate researchers to develop new methods for firm agility and digitalization measurement.

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Table 1. Definition of Variables Included in the Regression Models

Variable	Definition
Innovation Efficiency Variable	
DEA scores	Inputs: R&D investment, R&D personnel. Output: Number of granted patents.
SFA scores	Inputs: R&D investment, R&D personnel. Output: Number of granted patents.
Implicit Variables of Innovation Efficiency	
Input – R&D Investment	Total amount of spending on research and innovation.
Input – R&D Personnel	Total number of workers involved in R&D.
Output – Number of Granted Patents	Total number of granted patents (including invention, utility model, and design) per firm per year.
CEO Network Effects	
CEO Network Size	Total number of firms a CEO holds outside directorship in both listed and non-listed firms.
Control Variables	
Log Total Assets	Log of total assets
Leverage	The ratio of total debts to total assets.
Log Firm Age	Log of the number of years since the firm was established.
ROA	The ROA is calculated by dividing net income by total assets.

Table 2 Descriptive Statistics

	N	Mean	Std. Dev.	Min	Max
DEA	13,516	0.313011	0.1751418	0	1
SFA	13,516	0.264475	0.2053278	0	1
R&D Person	13,516	609.46	2042.276	0	42334
R&D Investment (in $ Billion)	13,516	0.168754364	0.8925941	0	73.839
R&D Output (No. of Granted Patents)	13,516	167.07	758.594	3	40182
CEO Network Size	13,516	1.941477	3.669904	0	69
Log Total Assets	13,516	24.01848	1.284637	20.47095	31.42907
Leverage	13,516	0.3690849	0.1982639	0.0116358	2.022782
Log Firm Age	13,516	2.621945	0.4548649	0	3.912023
ROA	13,516	0.032555	0.0364883	-0.7032342	0.2874986
Tobin's Q	13,516	0.5336062	0.6330018	-4.834386	23.45287

Note: The sample comprises 13,516 firm observations from 2007 to 2017 and presents the total observations, mean, standard deviation, minimum and maximum of the eleven-year data.

Table 3 Correlation Metrix

Variables	1	2	3	4	5	6	7	8
1 DEA	1							
2 SFA	0.9095	1						
3 CEO Network Size	0.0022	-0.032	1					
4 Log Total Assets	0.1704	0.064	0.0504	1				
5 Leverage	0.1208	0.0825	-0.0137	0.5054	1			
6 Log Firm Age	-0.1311	-0.2299	-0.001	0.2274	0.1951	1		
7 ROA	0.0045	0.0189	0.0226	-0.1784	-0.4172	-0.1458	1	
8 Tobin's Q	-0.1658	-0.1818	-0.0063	-0.3716	-0.0877	-0.0427	0.249	1

Table 4 Base Models & Robustness Checks

Model	Panel Data Fixed Effects		SGMM*	
Dependent variable	(1) DEA	(2) SFA	(3) DEA	(4) SFA
CEO Network Size	0.00121**	0.00161**	0.00165***	0.00602***
	(0.0006)	(0.0007)	(0.0008)	(0.0010)
Log Total Assets	-0.03722***	-0.0883***	-0.0278***	-0.0724***
	(0.0036)	(0.0044)	(0.0067)	(0.0083)
Leverage	0.08538***	0.113***	0.111***	0.128***
	(0.0154)	(0.0187)	(0.0255)	(0.0314)
Log Firm Age	-0.11840***	-0.256***	-0.230***	-0.413***
	(0.0080)	(0.0096)	(0.0146)	(0.0183)
ROA	0.15620***	0.238***	0.159*	0.184*
	(0.0603)	(0.0730)	(0.0891)	(0.1100)
Tobin's Q	-0.04788***	-0.0808***	-0.0516***	-0.0859***
	(0.0029)	(0.0035)	(0.0038)	(0.0047)
Lag1 Dependent Variable			0.252***	0.249***
			(0.0121)	(0.0115)
Constant	1.50411***	3.048***	1.488***	3.009***
	(0.0744)	(0.0900)	(0.1400)	(0.1740)
Observations	13,516	13,516	7,562	7,562
R-squared	0.10341	0.272		
Arellano-Bond AR(1)			(0.003)	(0.009)
Arellano-Bond AR(2)			(0.23)	(0.15)
Hansen test of over-identification (p-value)			(0.12)	(0.17)
Diff-in-Hansen tests of exogeneity (p-value)			(0.39)	(0.54)
* SGMM Instrument: Industry-median of Connect				

Note: The table reports regression coefficients and corrected standard errors (in parentheses). *, **, *** represent significance at the 10%, 5%, and 1% level, respectively.

Table 5 Impact of CEO Transition to Efficiency

Scenario	N	DEA		Mean	SFA		Mean
		Before transition	After transition	Difference	Before transition	After transition	Difference
When New CEO Holds Fewer Outside Directorships	87	0.3704	0.3082	-0.0622***	0.3462	0.2360	-0.1102***
When New CEO Holds More Outside Directorships	194	0.2972	0.3437	0.0465***	0.2197	0.3089	0.0892***

Table 6 The Annual Median Number of CEO Outside Directorships

Year	Median
2007	2
2008	2
2009	2
2010	2
2011	3
2012	2
2013	2
2014	2
2015	3
2016	3
2017	3

Table 7 Univariate Analysis at the Firm-Year Level

Group	Large Network Size	Small Network Size	
Observation	7,702	5,814	
Innovation Efficiency			**Mean Difference**
DEA	0.3218	0.2967	0.0250***
SFA	0.2725	0.2376	0.0349***
CEO Networks			
CEO Network Size	6.1096	1.2237	4.8859***
Firm-Level Characteristics			
Log Total Assets	24.00772	24.16745	-0.1597***
Leverage	0.3525	0.3778	-0.0253***
Log Firm Age	2.585502	2.65774	-0.0722***
ROA	0.0349	0.0326	0.0022***
Tobin's Q	0.5155	0.5533	-0.0378**

Note: *, **, *** represent significance at the 10%, 5%, and 1% level, respectively.

Table 8 **Comparison of Impacts of Large- & Small-Network Size on Efficiency (Panel Data, Fixed Effects)**

Model Dependent Variable	Large Network Size		Small Network Size		Full Sample Size	
	(1) DEA	(2) SFA	(3) DEA	(4) SFA	(5) DEA	(6) SFA
CEO Network Size	0.000335	-0.000361	0.0342***	0.0575***	0.00212**	0.00307***
	(0.0009)	(0.0010)	(0.0109)	(0.0128)	(0.0008)	(0.0010)
CEO Network Size Squared					-0.00004	-0.0000631*
					(0.0000)	(0.0000)
Log Total Assets	-0.0611***	-0.116***	-0.00545	-0.0391***	-0.03716***	-0.0883***
	(0.0086)	(0.0104)	(0.0109)	(0.0129)	(0.0036)	(0.0044)
Leverage	0.0484	0.0374	0.00884	0.0729	0.08512***	0.113***
	(0.0345)	(0.0417)	(0.0458)	(0.0541)	(0.0154)	(0.0187)
Log Firm Age	-0.114***	-0.271***	-0.214***	-0.414***	-0.11901***	-0.257***
	(0.0200)	(0.0242)	(0.0231)	(0.0273)	(0.0080)	(0.0096)
ROA	0.136	0.331*	0.305*	0.368*	0.15727***	0.240***
	(0.1490)	(0.1800)	(0.1630)	(0.1930)	(0.0603)	(0.0730)
Tobin's Q	-0.0632***	-0.105***	-0.0168***	-0.0295***	-0.04784***	-0.0807***
	(0.0077)	(0.0093)	(0.0047)	(0.0056)	(0.0029)	(0.0035)
Constant	2.093***	3.778***	1.034***	2.330***	1.50319***	3.046***
	-0.175	-0.211	-0.229	-0.27	(0.0744)	(0.0900)
Observations	7,702	7,702	5,814	5,814	13,516	13,516
R-squared	0.127	0.305	0.127	0.299	0.10359	0.272

Note: The table reports regression coefficients and corrected standard errors (in parentheses). *, **, *** represent significance at the 10%, 5%, and 1% level, respectively.