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Corporate Governance Indicators and Innovation in the Chinese Market

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Abstract: The importance of innovation as an indispensable driving force for the development of a quality economy, for the sustainability of national economies and for the support of enterprises in breaking through development bottlenecks cannot be overstated. Innovation is a key growth strategy for all businesses. It is centered on the chief executive officer (CEO) and is directly related to the cognitive level and decision-making preferences of executives. Based on the principal-agent theory and Upper Echelons Theory, this paper constructs a model to evaluate the impact of CEOs on corporate innovation using a sample of Chinese listed companies from 2008 to 2022. Based on China's political and economic system, this paper selects six relevant characteristics of CEOs, including gender, age, educational background, tenure, compensation and political affiliation to decide whether the CEO is suitable for the firm. At the same time, this paper also measures corporate innovation standards by the number of patents filed by the company, and thus finds that the CEO index has a positive and significant impact on corporate innovation. In addition, in order to address the endogeneity issue, the paper also applies a series of robustness tests, including alternative measures of firm innovation and alternative models (Poisson models), and finds that the results are consistent with the main regression results. Finally, the paper provides empirical evidence as a means of demonstrating the key driving role played by CEOs in corporate innovation. The implications of the above findings for corporate governance, including board shareholders and policymakers, are clear.

Keywords: Corporate innovation, corporate governance, Chinese market.

1. Introduction

Innovation is a driving force for sustainable socio-economic development for a country that can quickly boost its economy. Innovation plays a vital role in the sustainable development of enterprises and their success in competition. As a core system serving the national innovation system, firms are an indispensable part of developing overall innovation capability for the country (Johannessen et al., 2001). Therefore, research on corporate innovation is crucial for the future development of firms as well as for the growth of national economies.

Firm innovation, as a fundamental growth strategy of a firm, is closely related to the cognitive level and decision-making preferences of executives, especially CEOs (Sarfraz et al., 2020). Various characteristics of CEOs affect corporate innovation activities. Such as gender (Galasso and Simcoe, 2011), age and tenure (De Visser and Faems, 2015), educational or professional background (Ahn et al. 2017), and behavioral patterns in response to risk (Galasso and Simcoe, 2011).However, much of the literature only analyzes the impact of a single or a few CEO characteristics on firm innovation individually, Considering the possible multicollinearity, very little literature analyzes all the characteristics of CEOs in a comprehensive manner (Mazouz and Zhao 2019). Therefore, in this paper, we will use principal component analysis (PCA) to construct a CEO index and explore its relationship with corporate innovation in the Chinese market.

This paper chooses to study the Chinese market for the following reasons. In recent years, China has invested a lot of resources in the field of corporate innovation and formulated a series of policies used to encourage and support the independent innovation capability of enterprises (Hou et al., 2017) . Enterprise innovation has promoted the quality development of China's economy and improved China's ability of independent innovation. Compared to developed countries, China still lags behind in innovation (Lin et al., 2011) . Therefore, understanding the relationship between CEOs and firms' innovation can help Chinese firms take innovation to the next level, thus promoting national economic development. In addition, it is worth mentioning that Chinese firms are categorized into state-owned enterprises (SOEs) and non-state-owned enterprises (NSOEs). CEOs of SOEs are sometimes forced to change their tenure in case of poor performance (Zhu et al., 2016). This situation is not common in developed countries such as Europe and the United States. Therefore, in this paper, the research around CEO characteristics will be outlined with different evidence than in developed countries to complement the emerging markets.

This paper focuses on the relationship between CEO characteristics and corporate innovation in the Chinese market in 2008-2022. The paper successfully constructs a CEO index through principal component analysis and finds that the index is positively related to corporate innovation. In addition, the paper reveals a large amount of evidence on the positive impact of the CEO index on corporate innovation in Chinese listed companies. The results of the study are stable due to the large amount of data used as the basis, in which a series of alternative measures including endogeneity, innovation output and different modelsare applied.

However, when studies use R&D investment as an indicator to quantify firm innovation, the conclusions may suffer from a number of shortcomings and problems as follows. First, the link between R&D expenditures and innovation output may be nonlinear and may have uncertain lags, making it impossible to accurately measure firm innovation (Crosby, 2000). Second, R&D expenditure measures do not take into account important inventions by

private inventors or entrepreneurs (Donoso, 2017).Patents have become perhaps the most accurate measure of innovation compared to R&D expenditures (Bronzini and Piselli, 2016). Patents as are the outputs of the invention process, and by linking R&D activities, one can better measure firm innovation (Hasan and Tucci, 2010.). However, using patents to measure firms' innovation, the findings have drawbacks, such as poor cross-country comparability (Bottazzi and Peri, 2003). Therefore, this thesis focuses its discussion on one country only. Considering these factors, this paper argues that patents (i.e., innovation output) are a more appropriate measure of firm innovation, thus making the empirical findings of this paper more accurate.

2. Literature Review

2.1. Theoretical background

2.1.1. Principal-agent theory

The agency problem stems from the separation of ownership and control of the firm. Due to the asymmetry of information, it is difficult for the principal to determine whether the agent acts with the goal of maximizing the principal's interest, thus further deepening the agency problem. Jensen and Meckling (1976) define this conflict of interest as an agency problem existing between shareholders and managers. This type of agency problem arising from the conflict of interest between shareholders and managers is referred to as the first type of agency problem. In a study of the shareholding structure of firms in 27 developed economies, La Porta et al. (1999) found that firms in economies other than relatively intact investor-protected economies typically have relatively high levels of equity concentration. A second type of agency problem emerges when the firm's equity is no longer decentralized but is in the hands of a very small number or a single large shareholder. Since the content of this paper is directed at the relationship between the CEO and corporate innovation; the paper will therefore focus primarily on the first type of agency problem.

The principal-agent theory is of great importance in the field of corporate governance research. The theory provides a favorable analytical perspective for studying the characteristics and quality of corporate governance (Bhaumik et al., 2019). Prior research literature on empirical evidence related to agency issues (Aguilera and Crespi-Cladera, 2016) has provided sufficient evidence to show that corporate governance can significantly influence firm development under principal-agent theory. Although principal-agent theory is both practical and popular, it is still subject to various conditions (Shleifer and Vishny, 1997). Even based on this theory, studies have not provided enough evidence to prove the link between equity ownership of different constituent groups and firm performance (Dalton et al., 2003). However, it is undeniable that the principal-agent problem is a common problem in modern corporate governance. Therefore, principal-agent theory is a very worthwhile theory to refer to when studying corporate governance.

2.1.2. Upper Echelons Theory

With further exploration, it was found that senior executives have a significant impact on the process of selecting and implementing corporate strategies. The upper echelon theory, first proposed by Hambrick and Mason (1984), states that the psychological characteristics of executives, such as for the quantification of risk preference is very complex, so it is difficult to obtain the true inner thoughts of the interviewed executives in the experiment, and the data lacks a certain degree of objectivity. The theory suggests that it is difficult to quantify the psychological characteristics of executives such as risk appetite, and it is difficult to obtain real data reflecting the inner thoughts of the interviewed executives in the conclusion, and the data lacks objectivity. However, since executive personality and traits are easily recognizable and relatively objective, this may influence executives' perceptions, values, and risk preferences. This can also affect senior management's decision-making process and its impact on the company's operational decisions and company performance (Cucculelli and Ermini, 2013).

According to Rauch and Frese (2000), the risk appetite of business managers has a negative impact on business performance. Contrary to they, Willebrands (2012) et al. analyzed the relationship between managerial risk preferences and SMEs' performance in developing countries through an empirical study, and the results of the study showed that executives' risk preferences have a positive and positive impact on firm performance. In addition, Carpenter (2004) et al. suggested through their study that Upper Echelons Theory and principal-agent theory should be analyzed together compared to independent analysis. The Upper Echelons Theory adds a new dimension to the study of corporate governance by emphasizing the important influence of human psychological factors on corporate decision-making. Therefore, this paper will consider a combination of the two theories, principal-agent theory and Upper Echelons Theory, to better understand the relationship between firms' strategic decisions and their executive teams when examining the impact of CEOs and boards of directors on innovation.

2.2. Hypothesis Development

CEO index and corporate innovation

The CEO, as the important decision maker of the firm, has significant control over the allocation of resources for R&D activities.The CEO is primarily responsible for the planning and design of the firm's innovation strategy. Innovation is crucial to corporate survival, and corporate innovation, as a high-risk activity, requires the investment of a large amount of corporate resources and managerial talent. Therefore, the CEO's personality, management style, and incentives may significantly influence the direction, focus, and progress of a firm's innovation activities (Barker III and Mueller, 2002). As a value decision maker in a firm's innovation activities, the CEO's risk aversion and short-sightedness will lead to reduced R&D expenditures, while the CEO can better serve his or her own interests at the expense of shareholder wealth. (Mezghanni, 2010). And for example, female executives are perceived to be more risk averse and less confident in themselves. (Faccio et al., 2016). CEOs of middle to senior age or with a long tenure are perceived to be generally more conservative and tend to be risk averse in their decision making, which may also lead to underfunding of investments in R&D projects with uncertain futures (Mezghanni, 2010).Simsek et al. (2005) argue that as CEOs grow older, they gain more experience and more confidence to adopt a more aggressive R&D investment strategies. However, González-Uribe and Groen-Xu (2017) present the opposite view to Mezghanni (2010), who find that by extending the term of the CEO's contract and patent citations by one year, patent citations will increase the benefits by 8%. This would indicate that as CEOs stay in office for longer periods of time, they positively impact on the growth of innovation activities

in their firms. Furthermore, in terms of educational background, CEOs with university degrees are more likely to invest heavily in R&D.

In addition to personal characteristics, CEO pay incentives have been identified as an important factor in regulating CEO behavior and influencing their management style and the corporate strategies they develop. In order to mitigate possible conflicts of interest and agency problems between managers and shareholders, Manso (2011) proposes a theoretical framework for incentive programs to encourage managers to be more innovative.CEO compensation programs are considered to be an important means of reducing conflicts of interest between managers and shareholders of a firm, while it also has a positive and significant impact on the firm's performance (Ozkan, N,. 2011).

Finally, as the subject of this paper is based on a specific market (i.e. the Chinese market), this study also considers the political connections of CEOs. By establishing political relationships, firms can obtain various benefits such as financing facilities and preferential treatment (Claessens et al., 2008) as well as lower effective tax rates (Adhikari et al., 2006). In developed markets such as Europe and the United States, political relationships between CEOs may bring the assurance and certainty needed for large-scale and high-risk exploratory corporate innovation investment programs. However, emerging markets still inevitably face high levels of policy uncertainty compared to developed markets.

In summary, scholars have obtained extensive research findings on CEO characteristics (including gender, age, educational background, tenure, and compensation). However, most of the existing literature is limited to analyzing one or several aspects of CEO characteristics and lacks comprehensive research and analysis. In addition, the results of the impact of certain variables, such as CEO age and tenure, on R&D investment have not yet led to more unified research conclusions. Therefore, based on the principal-agent theory, Upper Echelons Theory and innovation theory, this paper identifies six factors (gender, age, educational background, tenure, salary, and political relations) thus forming the CEO index, and then analyzes its impact on corporate innovation activities in the light of China's political and economic system. Therefore, the hypotheses of this thesis are:

H1: CEO index can significantly influence corporate innovation

3. Data and Models

3.1. Sample

This paper selects a sample of all Chinese listed companies from 2008 to 2022 to analyze the relationship between corporate governance and innovation in a municipal context.In 2007, the Chinese government issued a new accounting measure that requires all listed companies to disclose their R&D-related information, i.e. innovation. Therefore, this paper chooses 2008 as the starting year. In this paper, two existing databases are selected for data collection. The first database is the China Economic and Financial Research Database (known as CSMAR). This database contains almost all the information about Chinese companies. It contains 18 series of research data, including the stock market, Chinese listed companies, fund market, and bond market. This database is also often used for other related studies (Zhang Zairan, 2023). The second database is the China National Intellectual Property Office (CNIPA), which provides innovation data for all Chinese firms. Previous studies have also used this database to empirically analyze the innovation of Chinese firms. For example, Jiang et al. (2020) utilize the number of patent applications collected from CNIPA in 2011 to measure innovation and thus investigate the impact of stakeholder relationship capabilities on firms' innovation.

In order to ensure the reliability of the research results, the following screening and processing steps have been carried out in this paper. First, after collecting all the data, companies belonging to the financial sector were excluded from this paper due to their different structure from other companies. Subsequently, samples containing observations with missing variables were also removed to ensure the completeness and consistency of the sample. In this paper, the method of (Ren et al., 2021) was used to winnow all data by 1% and 99% and regression analysis was performed using STATA software. The final sample contains 23,877 observations from 2,811 independent firms.

3.2. Estimation of variables

3.2.1. Measurement of innovation in firms

Previous research around this topic has mainly used R&D as a reasonable proxy for measuring innovation (Li Guang, Ling Ying, 2023). However, such metrics can only show a firm's inputs to innovation and do not directly reflect actual innovation activities. In addition, R&D departments are subject to revenue management (Seybert, 2010). Therefore, this thesis uses the number of patents to quantify corporate innovation based on Nie Changfei et al. (2022).

According to the Chinese Patent Law, patents can be divided into three categories, invention, utility model and design, which are significantly different in terms of examination period, protection period and authorization conditions. Invention patents have a 20-year protection period, while the other two types of patents have only 10 years. (Cheung and Ping, 2004). Invention patents belong to innovative technology, and innovative products and processes require novelty, inventiveness and utility. Utility model patents are used for applied technology that changes the structure of a product, such as the physical characteristics of the shape or structure, in which case they help the product to be more suitable for use by customers. In addition, design patents are used where the product itself is redesigned and researched for aesthetics and applications, such as patterns and colors, which make the product more attractive and suitable for industrial applications. Moreover, design patents are of the lowest quality among the three types of patents (Sun et al., 2008). Due to the limitations of technological innovation around design patents, this paper will refer to relevant literature and use invention patents and utility model patents to construct an innovation metric model. (Fang et al, 2017).

As there is an 18-month lag between the filing of a patent application and its granting. Meanwhile, compared with the number of patents granted, it is more stable to use the number of patent applications to reflect the ability of a unit to innovate. In this paper, we will use the number of patent applications as the main proxy for firm innovation. This is also due to the fact that the number of patents granted has sometimes had an impact on firms' performance and does not actually reflect the true innovation activity in a given year. This measure is

consistent with other literature (Lai Wenjing and Manny Cheng, 2016).

3.2.2. Measurement of the CEO Index

Simply putting all the CEO characteristics together may lead to the problem of multicollinearity in the regression, which may bias the estimation results. Therefore, to overcome this limitation, this dissertation draws on Nemlioglu and Mallick (2021) to build a CEO index using principal component analysis (PCA). This thesis identifies six characteristics of CEOs, namely gender, age, educational background, tenure, compensation and political affiliation of CEOs.

Using CEO gender as a dummy variable with a value of 1 if the CEO is male and 0 if the CEO is female (Huang and Kisgen, 2013). Take the natural logarithm of the CEO's age (Faccio et al., 2016). Since the educational background of the CEO is a dummy variable, it is taken as 1 if when the CEO has a graduate degree or higher and 0 otherwise (De Visser and Faems, 2015). This study uses the natural logarithm of the number of years the CEO has been in office to measure CEO tenure (Chen et al., 2019).CEO's compensation is the natural logarithm of the number of years the CEO has been in office in terms of $10,000 (Vieito, 2012).The CEO's political affiliation variable is a dummy variable that equals 1 if there is a political affiliation, otherwise it equals 0 (Wu et al., 2018).CEO's political affiliation variable is a dummy variable that equals 1 if there is a political affiliation and 0 otherwise.

The initial tests for Principal Component Analysis (PCA) method are KMO and Bartlett's test (Karabulut, 2015) to determine whether the sample is fit for purpose. The study yielded a test statistic of 0.856, which is above the critical value, indicating that the sample is suitable for the method. Subsequently, different weights were calculated using the relevant formulae to calculate the different weights. Table 1 provides a detailed description of the results.

Table 1. Principal component analysis

KMO and Bartlett Test		0.856	
variant	load factor	eigenvalue (math.)	weights
Gender of Chief Executive Officer	-0.039	1.41	-0.033
Age of Chief Executive Officer	0.598		0.504
Chief Executive Officer Educational Background	0.55		0.463
Chief Executive Officer remuneration	0.175		0.147
Chief Executive Officer Political Relations	0.379		0.319
Term of office of the Chief Executive Officer	0.757		0.638

This table reports the results of the principal component analysis of CEO characteristics. A detailed description of the CEO characteristics can be found in Appendix 1.

Thus, the CEO index can be written as:

$$\begin{aligned}\text{CEO index} = {} & -0.033 * \text{CEO gender} + 0.504 * \text{CEO age} \\ & + 0.463 * \text{CEO education background} \\ & + 0.147 * \text{CEO remuneration} + 0.319 \\ & * \text{CEO political relations} + 0.638 \\ & * \text{CEO term}\end{aligned}$$

3.2.3. Control variables

This paper controls for a set of firm characteristics that have been shown to affect corporate innovation. The control variables in this paper are as follows. The first control variable is firm size, which can be measured by taking the natural logarithm of a firm's total assets (in millions). Li Jian and Gong Yuxia (2023) explored the relationship between firm size and innovation and found that firm size possesses a facilitating effect on firms' innovation performance, and the facilitating effect on firms' innovation performance is greater when firm size is larger. Therefore, the predictive sign of this variable is positive. The second control variable is firm age. Firm age is determined as the natural logarithm of the number of years it has been in business. Age is considered a fundamental determinant of firm innovation due to the learning effect (Fan and Wang, 2019), i.e., younger firms have a greater chance of being affected by the learning effect and show a tendency to invest more firm resources (human and financial) in R&D projects (Coad et al., 2016). Bao Xiaona and Fan Xiao-Nan found (2023) that for brick-and-mortar firms, financialization has a negative impact on firms' innovation decisions and innovation investment, and the higher the degree of financialization, the lower the firm's innovation investment. Therefore, this study hypothesizes a negative correlation between firm age and its innovation. The third control variable is firm profitability, which is measured by return on assets (ROA).Artz et al. (2010) used return on assets (ROA) to measure the individual impact of innovation on firm performance, which led to the derivation that innovation favors firm capabilities. Therefore, this paper predicts that this control variable is positive.

He and Tian (2013) show that excessive pressure on corporate executives during analyst tracking promotes the accomplishment of short-term goals (e.g., the pursuit of short-term performance), but also affects the firm's investment in long-term program innovation. Therefore, the fourth control variable in this thesis is chosen to take the natural logarithm of the number of financial tracking analysts. Here, it refers to the number of firm tracking analysts in the market in each year. In addition, the fifth control variable is leverage, which is the ratio of total debt to total assets. In analyzing the relationship between firms' debt levels and R&D expenditures, Singh and Faircloth (2005) found a strong negative correlation between the level of financial leverage and the level of R&D expenditures. This implies that higher (lower) leverage may lead to lower (higher) firm innovation. The sixth control variable in this paper is a measure of a firm's audit quality, which is equal to 1 if it is the selection of a Big

4 accounting firm for auditing services in the specified fiscal year, and 0 otherwise.Nguyen et al. (2020) find that firms with high audit quality have a greater number of short-term institutional investors and greater analyst tracking coverage. In other words, audit quality is negatively related to firm innovation. Meanwhile, by revolutionizing the mixed ownership system of SOEs, the innovation efficiency of SOEs increases, and SOEs are able to gain from R&D expenditures by obtaining efficient patented results. Therefore, this paper finally considers adding the control variable of state-owned enterprises. If the ultimate controlling shareholder of the enterprise is the state, the variable is equal to 1; otherwise, the variable is equal to 0.

3.3. Modeling

The following regression equation is proposed in this paper to test the hypothesis.

$$Y_{i,t+1} = \beta_0 + \beta_1 \text{CEO Index}_{i,t} + \beta_j \text{Controls}_{i,t} + \varepsilon_{i,t}$$

$Y_{i,t+1}$ This refers to firm innovation, as measured by Ln(Invention+1) and Ln(Invention+Utility+1). To avoid firms having zero innovation output in a given year, the starting value of invention in the default equation is automatically added to 1. The CEO index is the main independent variable generated using the PCA methodology. Controls include firm size, firm age, return on equity, leverage, Big 4 accounting firms, number of tracking analysts, and state-owned enterprises. To avoid simultaneous bias (Chen et al., 2018), this dissertation advances the dependent variable by one year while including control year and industry fixed effects.

4. Empirical Results and Analysis

4.1. Descriptive statistics

Table 2 presents the distribution of firms' innovations by year (Table A) and by industry (Table B). The table details the number of invention patents as well as the number of invention and utility model patents excluding financial firms in the sample by year (Table A) and by industry (Table B). In particular, the sample of invention and utility model patents from 2008-2022 is taken from CNIPA.The results in Table A show that patents have increased dramatically over the past years, with invention patents increasing from the original 3.615 in 2008 to 20.41 in 2022. Among them, the value in 2018 peaked at 5 times the original value. Similarly, due to 2016, innovation was listed as one of the most important themes. It became the main reason why the number of invention patents and utility model patents showed the same trend in 2017 and 2018, with a significant increase of 440% and 492%, respectively. Recently, General Secretary Xi Jinping emphasized that the implementation of the new development concept is the road to China's development and growth in the new era. It is necessary to insist that innovation is the first driving force and that it is central to China's modernization. There exists a positive incentive effect of Chinese government innovation subsidies on corporate innovation (Qi Yongxin , 2021). As a result, both invention patents and utility model patents of Chinese listed companies are steadily increasing under the impetus of Chinese government policies.

Panel B reports the distribution of innovations across industries, with both scientific research and technology services ranking in the top two in terms of the number of patents. This is due to the fact that China's State Council defines the "scientific and technological service industry as a new industry that provides intellectual services to the society by using modern scientific and technological knowledge, modern technology and analytical research methods, as well as experience, information and other elements" (Liu, 2014). According to the official website of the Chinese government, the executive meeting of the State Council clearly pointed out that innovation is the driving force for the necessary strategic support of the scientific research and technology service industry (Liu, 2014). Therefore, the Chinese government has created a favorable policy environment for the development of the science and technology service industry. With the policy support of the Chinese government, the science and technology service industry has developed significantly as one of the important elements of the high-tech industry.

The technological innovation capabilities of service sector firms are relatively low compared to those of research and technology services. This is due to the fact that service sector firms invest more resources in training activities and organizational change and interact more with traditional technology providers (Yam et al., 2011). On the contrary, when firms invest less resources in R&D, firms rarely use patents and interact less with science and technology organizations (Evangelista, 2006). In addition, few accommodation and food service firms invest resources in R&D because they are primarily service-oriented. In the table, the Accommodation and Food Service sector has the lowest number of patents for inventions and patents for inventions and utility models, which are 0.405 and 0.466, respectively. Therefore, this is in line with the actual situation.

Table 3 lists in detail the descriptive statistics of the main variables used in this paper, including innovation, CEO characteristics and firm characteristics. From the table, it is evident that each company has an average of 5.26 invention patents per year and 10.376 invention and utility model patent applications. In other words, the number of invention patent applications and utility model patent applications are similar, and the number of invention patent applications and utility model patent applications are equally important for Chinese listed companies. In addition, Table 3 shows that an average of 4.71 invention patents and 12.54 utility model patents are granted each year. Obviously, the utility model specialty impact may be more influential for the sample companies. This is possibly due to the lag time between patent application and grant lengthening in China after 2011, and the lag time between patent application and grant showing a significant downward trend (Lin et al., 2021).Kong et al. (2020) studied listed companies in China's energy industry and found that the number of utility model patents granted was higher than the number of invention patents granted in China. The results of this study concluded that the granting of invention patents by companies requires a longer period of time and stricter judging criteria.

Table 2. Distribution of firms' innovations

Table A. Annual distribution		
	Patents for inventions	Invention and utility patents
2008	3.615	5.414
2009	2.621	4.890
2010	4.374	7.236
2011	4.847	8.717
2012	5.204	9.742
2013	5.658	10.539
2014	5.191	10.466
2015	3.877	7.850
2016	9.338	19.355
2017	14.752	29.243
2018	15.619	32.038
2019	9.039	11.837
2020	16.46	21.52
2021	18.73	26.37
2022	20.41	31.36
Table B. Industry Distribution		
Transportation, storage and postal services	1.149	2.239
gastronomy	0.405	0.466
Information transmission, software and information technology services industry	5.860	7.357
Agriculture, forestry, livestock, fisheries	1.684	2.850
fabrication	18.961	41.926
Health and social work	2.835	6.153
building industry	9.265	17.619
Real Estate	0.830	1.272
Wholesale and retail	1.280	2.071
teach	0.667	0.920
Culture, sports and entertainment industries	1.288	1.826
Water, environment and utilities management industry	2.636	5.499
Production and supply of electricity, heat, gas and water	2.104	5.158
Research and technology services	23.878	43.037
Rental and business services	0.720	1.242
synthesis	2.407	3.995
mining industry	4.039	8.731

This table reports corporate innovation throughout the year and by industry. The sampling period is between 2008 and 2022.

Regarding the characteristics of CEOs, the average gender of CEOs reported in Table 3 is 0.939, which means that in the sample of this paper, males account for 94% of CEOs, with an inconsistent ratio of males to females, a result that is consistent with the literature. For example, Zhu Wenli et al. (2017) selected China's A-share listed companies from 2012 to 2014 as the study population and collected that the percentage of companies with female executives is 94.04%. However, Huang and Kisgen (2013) emphasized that women accounted for only 2% of CEOs in large listed companies in the United States. Nonetheless, the gender ratio of CEOs still varies considerably and is predominantly male, and women remain relatively few in top management positions in companies for a variety of reasons.The average (median) age of CEOs is 50.152 (50) years old. Table 3 shows that the CEO's annual salary is about 744,600 yen.De Andrés et al. (2017) collected information on listed companies in major economies in Western Europe from 1999-2007. In this sample, the average direct annual salary of CEOs was US$1,326,312. It can be seen that there is still a large gap between the income of Chinese CEOs and that of CEOs in developed countries. According to the report in Table 3, 8.4% of CEOs in the sample of this paper have political connections. In contrast, based on panel data of 1,293 Chinese listed companies from 2010-2014, Wang et al. (2018) report that 15.5% of CEOs have political connections. Overall, CEOs with political connections in Chinese listed companies remain a minority. In addition, Lin et al. (2011) argue that CEO tenure is about 1.8 years, which is consistent with the findings of this thesis when studying the Chinese market. This suggests that the tenure of CEOs in Chinese listed companies is relatively short. Finally, the CEO index is a combination of six factors (gender, age, educational background, compensation, political connections, and tenure).

In terms of control variables (firm characteristics), according to Table 3, the average size of the firms is 11045.649 (in millions of base), the average age is 16.474 years, ROA is 0.049, leverage is 0.411, Big 4 Accounting Firms is 0.057, tracking analysts is 9.009, and state-owned enterprises is 0.348.

Table 3. Descriptive statistics

variant	observed value	average value	(statistics) standard deviation	minimum value	upper quartile	maximum value
			blaze new trails			
Application for Invention	23877	5.260	13.340	0.368	1.104	101.535
Invention and Utility Model Applications	23877	10.376	25.942	0.368	2.207	191.665
Authorization of inventions	23877	4.711	12.596	0.368	0.736	92.338
Invention and utility model authorizations	23877	17.247	44.881	0.368	2.943	330.724
			Characteristics of the Chief Executive Officer			
distinguishing between the sexes	23877	0.939	0.240	0.000	1.000	1.000
(a person's) age	23877	50.152	6.418	34.000	50.000	66.000
educational background	23877	0.832	0.374	0.000	1.000	1.000
remunerations	23877	74.457	70.269	1.000	55.400	451.000
political relations	23877	0.084	0.277	0.000	0.000	1.000
term of office	23877	1.276	0.668	0.080	1.253	2.680
Chief Executive Officer Index	23877	4.866	0.692	2.627	4.897	6.383
			Company Characteristics			
Company size	23877	11045.649	27909.623	411.155	3128.537	210000
Company age	23877	16.474	5.401	6.000	16.000	32.000
return on assets	23877	0.049	0.060	-0.218	0.044	0.228
Leverage	23877	0.411	0.204	0.047	0.404	0.862
Big 4 accounting firms	23877	0.057	0.233	0.000	0.000	1.000
Tracking Analyst	23877	9.009	9.544	1.000	5.000	43.000
nationalized business	23877	0.348	0.476	0.000	0.000	1.000

This table reports descriptive statistics for this sample for the period 2008 to 2022. Its dependent variable is firm innovation. A detailed description of these variables can be found in Appendix 1.

4.2. Correlation matrix

The correlation between the variables is shown in Table 4. The correlation between the CEO index and corporate innovation is positive, which is in line with the hypothesis. In addition, this paper finds that the critical value of the correlation coefficient between the two variables is not higher than 0.7, which indicates that the multicollinearity of the model studied in this paper is less likely to bias the regression results.

Table 4. Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Application for Invention	(1)	1									
Invention and Utility Model Applications	(2)	0.932*	1								
Chief Executive Officer Index	(3)	0.191*	0.174*	1							
Company size	(4)	0.244*	0.214*	0.157*	1						
Company age	(5)	0.090*	0.066*	0.181*	0.222*	1					
return on assets	(6)	0.034*	0.031*	0.093*	-0.097*	-0.164*	1				
crowbar	(7)	0.029*	0.022*	-0.025*	0.544*	0.169*	-0.386*	1			
Big 4 accounting firms	(8)	0.087*	0.068*	0.047*	0.370*	0.004	0.025*	0.129*	1		
Tracking Analyst	(9)	0.200*	0.180*	0.143*	0.327*	-0.152*	0.378*	-0.030*	0.167*	1	
nationalized business	(10)	-0.056*	-0.091*	-0.134*	0.382*	0.091*	-0.094*	-0.298*	0.165*	0.013*	1

This table reports the correlation matrix for the sample for the period 2008 to 2022. The dependent variable is firm innovation, and a detailed description of these variables can be found in annex 1.
*Represents the level of significance at the 5% level.

4.3. Main regression results

The main regression results are shown in Table 5.At the 1% significant level, the CEO index is able to positively and statistically influence the number of corporate invention patent applications. This finding is consistent with the findings of Sarfraz et al. (2020), who compiled an index of corporate environmental performance using 1,058 Chinese listed companies over the period 2015-2019 and obtained similar results. That is, the role of the CEO is crucial in stimulating firms' innovation output. Notably, these results also provide some economic implications. For example, the coefficient 0.11 in column (2) suggests that for every percentage point increase in the CEO index, there will be a corresponding increase of 11% in the number of invention patent applications. And in column (4), the coefficient 0.097 indicates that for every percentage point increase in the CEO index, the number of utility invention patent applications will increase by 9.7%. In addition, through the comparison of the coefficients, this paper finds that the CEO index affects invention patents and utility patents to a similar extent, indicating that enterprises attach the same importance to these two kinds of patents.

In terms of control variables, firm size is positively correlated with Ln(Invention+1) and Ln(Invention+Utility+1) at a significant level of 1%, indicating that the size of a firm has a significant effect on its innovation. Larger firms are more inclined to apply for patents and invest more resources in corporate innovation activities, which is consistent with the empirical results of Fossas-Olalla et al. (2015). In addition, firm age is negatively correlated with Ln(Invention+1) and Ln(Invention+Utility+1), and the difference between the indicators reaches 1% significance, which suggests that the older the firm, the weaker the firm's innovation capacity is.The results of Coad et al.'s (2016) study show that young firms invest more in R&D than mature firms. The relationship between the top four audit firms and the innovation indicator is significantly positive, indicating that firms audited by the top four audit firms are able to achieve better innovation outcomes.Above 1%, the regression coefficient between tracking analysts and firm innovation is positive and significant, suggesting that an increase in tracking analysts affects an increase in firms' future patent filings. In summary, these results are generally consistent with previous studies, indicating that the above results strongly support the hypotheses of this dissertation and agree that the CEO index can significantly influence corporate innovation.

Table 5.

variant	Ln(invention+1)_application		Ln (invention + utility application + 1)_application	
	(1)	(2)	(3)	(4)
Chief Executive Officer Index	0.244***	0.110***	0.240***	0.097***
	(17.97)	(8.70)	(15.84)	(6.76)
Company size		0.291***		0.317***
		(27.71)		(26.63)
Company age		-0.075***		-0.159***
		(-2.87)		(-5.20)
return on assets		0.027		0.033
		(0.18)		(0.19)
Leverage		-0.025		0.106*
		(-0.49)		(1.80)
Big 4 accounting firms		0.119***		0.089*
		(2.83)		(1.91)
Tracking Analyst		0.161***		0.162***
		(19.47)		(17.18)
nationalized business		0.009		-0.097***
		(0.48)		(-4.43)
Constant	-1.265***	-3.283***	-1.178***	-3.125***
	(-17.80)	(-30.05)	(-14.28)	(-25.00)
observed value	23,877	23,877	23,877	23,877
Adj-R2	0.244	0.291	0.339	0.369
vintage effect	Yes	Yes	Yes	Yes
industry effect	Yes	Yes	Yes	Yes

This table reports the main regression results for the sample over the period 2008 to 2022. The dependent variable is firm innovation and a detailed description of these variables can be found in annex 1.
*** represents 1%, ** represents 5% and * represents 10% level of significance.

4.4. Endogeneity

Past literature suggests that corporate innovation may also affect CEOs.Using a sample of Chinese listed firms from 2009 to 2015, Zhou and Pan (2018) find that corporate innovation reduces the risk of stock price crash caused by top management. When faced with the demand for financing due to corporate innovation, management will release more information about the firm to the public to win investors' trust and reduce the risk of stock price plunge (Zhou and Pan, 2018). This suggests that corporate innovation affects CEOs' managerial behavior.Biscotti et al. (2018) state that by changing the CEO, the firm structure and strategy may change. the change of CEO, especially when the new CEO is an outsider, the firm innovation can be affected. All of this research evidence suggests that there is an endogenous relationship between the CEO index and firm innovation.

To further ensure that the regression results are unbiased, and to overcome this endogeneity problem, this paper uses the

2sls method.The only variable in the 2sls instrumental variable method is the instrumental variable (IV), with which the endogenous variable (e.g., the CEO index) should be correlated with the IV, but the dependent variable (e.g., firm innovation) has a low correlation with it.El Ghoul et al. (2011) and Benlemlih and Bitar (2016) argue that CEO characteristics are different across regions because individuals in CEO positions usually have families and are therefore less likely to choose firms that are far from their home location. Therefore, "province" becomes a good instrumental variable in this case, as firm innovation is unlikely to differ by the CEO index at the provincial level. Therefore, this thesis follows Jiang et al. (2017) and uses the provincial average of the CEO index as an instrumental variable with a 2sls regression.

This paper reports the results of the 2sls regression in Table 6. The results show that in the first stage, the coefficient (0.846) of the instrumental variable (CEO index provincial average) is positive and significant at the 1% level. In addition, the instrumental variable (CEO index province average) is not a weak instrumental variable in this paper because the statistic is larger than the critical value set by Stock et al. (2005). The results of the second stage are consistent with the results of the main regression, and the paper concludes that the positive correlation between the CEO index and firm innovation is solid after accounting for endogeneity issues.

Table 6.

	Phase I	Phase II	
variant	Chief Executive Officer Index (1)	Ln(invention+1)_application (2)	Ln (invention + utility application + 1)_application (3)
Provincial average CEO index	0.846***		
	(24.35)		
Chief Executive Officer Index		0.897***	1.080***
		(11.17)	(11.35)
Company size	0.073***	0.236***	0.248***
	(13.45)	(18.92)	(17.14)
Company age	0.106***	-0.171***	-0.279***
	(8.25)	(-5.72)	(-7.92)
return on assets	0.958***	-0.759***	-0.951***
	(10.99)	(-4.12)	(-4.42)
Leverage	-0.083***	0.055	0.205***
	(-2.94)	(0.97)	(3.14)
Big 4 accounting firms	-0.003	0.101**	0.067
	(-0.14)	(2.24)	(1.31)
Tracking Analyst	0.075***	0.098***	0.084***
	(17.15)	(8.94)	(6.53)
nationalized business	-0.128***	0.136***	0.062**
	(-12.50)	(5.63)	(2.21)
Constant	-0.292*	-5.963***	-6.474***
	(-1.85)	(-20.32)	(-18.69)
observed value	23,877	23,877	23,877
Adj-R2	0.215	0.223	0.235
Cragg-Donald Wald F statistic	673.271***		
vintage effect	Yes	Yes	Yes
industry effect	Yes	Yes	Yes

This table reports the results of 2 SLS regressions for the sample over the period 2008 to 2022. Its dependent variable is firm innovation. All variables are explained in Appendix 1.
*** represents 1%, ** represents 5% and * represents 10% level of significance.

4.5. Robustness checks

To further ensure the reliability of the results, this paper conducts a series of further robustness checks, including the use of other measures of firm innovation and different models. Among them, Table 7 reports the results of regressions using patent grants as the dependent variable (see Dang and Motohashi, 2015). In addition, according to Ferreira et al. (2019), Table 8 uses a Poisson model. Apparently, the results of these two tables are consistent with the main regression results, suggesting that the CEO index can positively affect corporate innovation.

Table 7. Alternative Measures of Firm Innovation

variant	Ln(invention+1)_authorization		Ln(Invention+Utility Application+1)_Authorization	
	(1)	(2)	(3)	(4)
Chief Executive Officer Index	0.235***	0.144***	0.274***	0.164***
	(17.89)	(11.14)	(16.07)	(9.64)
Company size		0.179***		0.159***
		(16.82)		(11.39)
Company age		0.100***		-0.007
		(3.87)		(-0.19)
return on assets		-1.353***		-2.112***
		(-9.24)		(-10.71)
Leverage		-0.513***		-0.410***
		(-10.14)		(-6.02)
Big 4 accounting firms		-0.134***		-0.266***
		(-3.17)		(-4.82)
Tracking Analyst		0.153***		0.220***
		(18.37)		(19.95)
nationalized business		-0.118***		-0.394***
		(-5.89)		(-14.83)
Constant	-1.467***	-2.650***	-1.591***	-2.072***
	(-21.90)	(-24.10)	(-17.11)	(-13.95)
observed value	23,877	23,877	23,877	23,877
Adj-R2	0.277	0.305	0.313	0.335
vintage effect	Yes	Yes	Yes	Yes
industry effect	Yes	Yes	Yes	Yes

This table reports the results of regressions using alternative measures of firm innovation. The sampling period is between 2008 and 2022. The dependent variable is firm innovation and a detailed explanation of these variables can be found in Appendix 1.
*** represents 1%, ** represents 5% and * represents 10% level of significance.

Table 8. Poisson

variant	patent application		Patent Licensing	
	devise	Invention and utility applications	devise	Invention and utility applications
Chief Executive Officer Index	0.074***	0.048***	0.105***	0.070***
	(8.55)	(6.47)	(9.95)	(8.33)
Company size	0.198***	0.165***	0.157***	0.086***
	(29.26)	(27.94)	(18.94)	(12.99)
Company age	-0.081***	-0.106***	0.051**	-0.025
	(-4.32)	(-6.47)	(2.27)	(-1.39)
return on assets	-0.136	-0.076	-1.282***	-1.070***
	(-1.30)	(-0.84)	(-11.08)	(-12.00)
Leverage	-0.043	0.040	-0.493***	-0.228***
	(-1.14)	(1.21)	(-11.19)	(-6.62)
Big 4 accounting firms	0.045*	0.031	-0.082**	-0.109***
	(1.95)	(1.47)	(-2.43)	(-3.64)
Tracking Analyst	0.111***	0.085***	0.130***	0.105***
	(19.18)	(17.01)	(18.86)	(19.86)
nationalized business	-0.015	-0.071***	-0.108***	-0.207***
	(-1.07)	(-5.84)	(-6.07)	(-14.36)
Constant	-3.713***	-2.620***	-4.269***	-2.065***
	(-34.39)	(-28.83)	(-32.11)	(-20.49)
N	23,877	23,877	23,877	23,877
Pseudo-R2	0.168	0.165	0.177	0.160
vintage effect	be	be	be	be
industry effect	be	be	be	be

This table reports the results of Poisson regressions for the sample over the period 2008 to 2022. The dependent variable is firm innovation and a detailed description of these variables can be found in annex 1.
*** represents 1%, ** represents 5% and * represents 10% level of significance.

5. Conclusion

This paper takes the specific position of CEO as the research object, and takes listed companies in China from 2008 to 2022 as the research sample, and starts from the perspective of CEO characteristics to comprehensively study the impact of CEO index on corporate innovation. It is found that CEO index has a positive impact on corporate innovation. In order to verify the reliability of the regression analysis results, this study conducted a series of tests, including the endogeneity test, replacing the measures of the independent variables, and replacing the model to make a regression analysis of all the variables. The results of regression analysis

are consistent with the main regression results, indicating that the results are robust. In addition, it is known through the study that the CEO index has a greater impact on corporate innovation compared to the board of directors index.

The sublicense results of this paper make some of the following contributions to the existing literature surrounding the relationship between CEO characteristics and firm innovation. In the previous literature, many scholars' analyses have tended to be limited to one or a few elements of CEO characteristics, and few scholars have comprehensively examined and analyzed the relationship that exists between CEO characteristics and firm innovation. This dissertation integrates the six major characteristics of CEOs (gender, age, educational background, tenure, compensation, and political affiliation) into a single index and comprehensively analyzes the impact of CEO characteristics on corporate innovation. Thus, this paper enriches a series of studies on the relationship between CEOs and corporate innovation. In addition, in order to ensure the reliability and accuracy of the empirical results, this paper measures a firm's innovation capability in terms of its innovation output (patents).As the maker and leader of strategic decisions in corporate governance, the CEO plays an important role in the future development of the firm. The findings of this paper show that CEOs have a significant impact on corporate innovation activities. Innovation is an important way to improve the core competitiveness of the firm and promote rapid growth. This data has important relevance for corporate governance including boards of directors, shareholders and policy makers. For example, analyzing the role of the CEO in the firm can help the firm to achieve optimal resource allocation and improve corporate governance, which in turn improves the firm's innovation performance. This contributes to the stability and sustainability of the firm and reduces the agency problem between managers and shareholders.

According to the theoretical analysis and experimental research conclusions in this paper, there are three suggestions for the management proposed by enterprises as follows. First, enterprises should both increase innovation investment and cultivate innovation ability. Enterprises should not suppress innovation failure, but should instead tolerate innovation failure. In this way, the management can positively face the challenges of enterprise innovation, increase enterprise innovation investment, and increase enterprise development potential. Second, enterprises should improve their internal governance system. Enterprises need to avoid excessive supervision and checks and balances by shareholders on the CEO, which leads to a decline in the CEO's work enthusiasm, which in turn causes the CEO's decision-making behavior to be conservative. In addition, enterprises need to implement a reasonable and effective incentive mechanism to improve the CEO's work enthusiasm and reduce the agency conflict between shareholders and the CEO. Third, companies need to build learning organizations and improve the education level of employees. Research has shown that CEOs with a higher level of literacy have a greater role in promoting innovation in the company. This fully explains that the more educated CEOs are more concerned about the long-term development of the enterprise, in the face of increasingly complex internal and external environments, they are more able to make their own professional knowledge based on their own intention of the development of the company is very favorable, so the enterprise should focus on the work ability of the management personnel, on the one hand, the enterprise in the introduction of talent, you can prioritize the higher education of the applicants. Especially in the recruitment of the company's middle and senior managers, enterprises should pay more attention to the candidate's academic level. In addition, training can also be utilized to enhance their professional knowledge so as to improve their actual management ability.

There are a number of limitations to the research in this paper. First, despite a series of robustness tests in this paper, there may still be some unobserved features that bias the findings of this paper. Second, this paper relies on patent application data to measure firm innovation. Although patents are a more accurate measure of innovation than R&D investment, the number of patent applications still has some shortcomings in measuring firm innovation.

In view of the limitations and shortcomings of this study, in the future, scholars can study the related issues in the following points, first, the other characteristics of CEOs as the main research. Second, expand the sample time period and increase the sample size. Meanwhile, from the perspective of industry categories, scholars can conduct comparative studies of high-tech industries, non-high-tech industries, and state-owned enterprises and non-state-owned enterprises. Finally, scholars can use a variety of empirical research tools or more indicators to analyze the relevant variables and argue the research hypotheses from various aspects to further enhance the credibility of the research results.

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Appendix

Variable Explanation		
Variable Name	Predict Sign	Explaination
	Dependent Variable	
Ln (Invention+1)_Application		The natural logarithm of the invention application patent plus one
Ln (Invention+Utility+1)_Application		The natural logarithm of the invention and utility application patent plus one
Ln (Invention+1)_Granted		The natural logarithm of the invention granted patent plus one
Ln (Invention+ Utility +1)_ Granted		The natural logarithm of the invention granted patent plus one
	CEO Characteristics	
Gender	+	A dummy variable that equals to one when a firm's CEO is male and zero otherwise
Age	-	A CEO's actual age takes natural logarithm
Eudcation	+	A dummy variable that equals ton one when a CEO has postgraduate degree or above and zero otherwise.
Compensation	+	A CEO's annual salary (in 10,000 base) taking the natural loargithm.
Political Connenction	+	A dummy variable that equals to one when the CEO has connection with the government and zero otherwise.
Tenure	+	A CEO's contract horizon (annual base) takes the natural logarithm.
CEO Index	+	Generate via the PCA method
	Board Characteristics	
Board Size	+	The natural logarithm number of the total number of the directors
Independence	+	The percentage of independent directors on board
Duality	-	A dummy variable that equals to one when the CEO also takes the chairman position.
Board Meeting	+	The natural logarithm number of the board meeting in one year
Ownership Concentration	+	The percentage shares hold by top ten shareholders
Board Index	+	Generate via the PCA method
Total Corporate Index	+	CEO Index * Board Index
	Firm Characteristics	
Firm Size	+	Natural logarithm number of a firm's total asset
Firm Age	-	Natural logarithm number of a firm's operational year
ROA	+	Net income divided by total asset
Leverage	+	Total debt divided by total asset
Big Four	+	A dummy variable that equasl to one when a firm is audited by top four audit companies and zero otherwise.
Analyst	+	Natural logarithm number of the number of the analyst follows in one company.
SOE	+	A dummy variable that equals to one when a firm is state-owned enterprise and zero otherwise.