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Are scholar-type CEOs more conducive to promoting industrial AI transformation of manufacturing companies?

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Abstract

Purpose – In order to effectively promote the deep integration of artificial intelligence and the real economy and empower real enterprises to improve quality and efficiency, this study regards the CEO as a high-end innovation resource and aims to empirically test the impact of scholar-type CEOs on the industrial artificial intelligence (AI) transformation of manufacturing enterprises.

Design/methodology/approach – Grounded on the upper echelons theory, this paper preliminarily selects A-share manufacturing listed companies in Shanghai Stock Exchange and Shenzhen Stock Exchange that are affiliated to enterprise groups from 2014 to 2020 as samples. Furthermore, the Logit regression is conducted to analyze the influence of scholar-type CEOs about industrial AI transformation.

Findings – The results show that scholar-type CEO plays a significant role in promoting industrial AI transformation. The parent-subsidiary corporations executives' ties positively moderates the impact of scholar-type CEOs on industrial AI transformation. Further, internal control quality plays a partial mediating role between scholar-type CEOs and industrial AI transformation. Compared with private enterprises, scholar-type CEOs play a stronger role in promoting industrial AI transformation of state-owned enterprises.

Originality/value – First, this paper expands the research related to the influencing factors of industrial AI transformation based on upper echelons theory and clarifies the influencing mechanism of scholar-type CEOs affecting industrial AI transformation from the perspective of executives' behavior. Second, this study further enriches the research framework on the economic consequences of scholar-type CEOs and provides a useful supplement to the research literature in the field of upper echelons theory. Third, this paper is not limited to a single enterprise but involves the management practice of resource allocation within the enterprise groups, further clarifies the internal logic of the decision-making of industrial AI transformation of listed companies within the framework of enterprise groups, providing theoretical reference for the scientific design of the governance mechanism of parent-subsidiary companies.

Keywords Corporate governance, Parent-subsidiary corporation, Industrial AI transformation, Academic experience

Paper type Research paper

1. Introduction

At present, the focus of world economic development is returning to the real economy, with the new generation of Internet information technology as the endogenous driving force, the development and application of artificial intelligence (AI) to promote the transformation and upgrading of traditional manufacturing industry has become a new path choice for most developed countries to seize the commanding heights of industrial competition, and many

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countries are planning and actively implementing policies (Kuo *et al.*, 2019; Osterrieder *et al.*, 2020; Zhong *et al.*, 2017). Compared with developed countries, China is faced with more complex environment and more arduous tasks in the process of promoting the deep integration of AI and real economy (Li *et al.*, 2017). How to explore the transformation route and breakthrough point has become an issue of the times that Chinese manufacturing enterprises must answer.

Industrial AI transformation refers to the upgrading of operation and management processes such as R&D, production, marketing, operation and maintenance by traditional manufacturing enterprises using typical products, technologies or solutions of AI (Zhong *et al.*, 2017), so as to achieve dynamic perception, interaction and execution, and then realize real-time management and optimization of the whole product life cycle. With the rapid development of the new generation of information technology, industrial AI transformation has become an inevitable trend for enterprises to shape their core competitiveness and achieve high-quality development of manufacturing industry (Lee *et al.*, 2022; Tsang and Lee, 2022; Marques *et al.*, 2017), and it is also an important guarantee for implementing the strategy of strengthening the country by manufacturing and building a domestic and international dual circulation system (He and Bai, 2021). Therefore, how to promote the formulation of industrial AI transformation strategies and outline the transformation strategy routes of different types of enterprises has become a major practical problem that academia and industry need to pay attention to for a long time.

Industrial AI transformation is an important decision deployment of enterprises and is closely related to executives (Zhou *et al.*, 2022). According to the upper echelons theory, the work experience of executives profoundly affects the cognitive structure and decision-making mode of executives, which is finally reflected in corporate behavioral decisions (Saeed *et al.*, 2022; Hermano and Martin-Cruz, 2016; Schoar and Zuo, 2017). Among them, academic experience, as a special and important work experience of CEO, has the characteristics of rigor and long-term, which has a profound impact on the value shaping and behavior pattern of corporate CEOs (Sun *et al.*, 2021). In recent years, more and more scientific researchers have entered the leadership of enterprises to hold key positions such as CEOs, and the widespread existence of scholar-type CEOs has become a unique phenomenon in the process of China's economic reform (Shen *et al.*, 2020; Qian and Li, 2017). Under the policy background of deepening the promotion and application of intelligent manufacturing in China, whether the CEO of manufacturing enterprises should be a professional with academic experience, and whether the CEO's academic experience will affect the industry of listed subsidiaries, the relevant research is still lacking, and it is urgent to open the "black box" between scholar-type CEOs and industrial AI transformation of manufacturing enterprises.

This study focuses on the following questions: What is the impact of scholar-type CEOs on industrial AI transformation? And what is the mechanism of its impact? Further, enterprise groups composed of numerous subsidiaries play pivotal roles in economic growth, while listed subsidiaries, as subsystems embedded in enterprise groups, can realize resource sharing within enterprise groups (Min *et al.*, 2022; Zheng *et al.*, 2022; Dou *et al.*, 2021). What are the differences in the performance of listed subsidiaries in enterprise groups in developing and applying AI as opposed to independent or single companies?

Based on the above thinking, this article is sampled by the listed manufacturing companies belonging to enterprise groups in Shanghai Stock Exchange and Shenzhen Stock Exchange from 2014 to 2020, and from the special situation of parent-subsidiary corporate governance, empirically tests the impact of scholar-type CEOs on the industrial AI transformation of manufacturing enterprises and the contingency situation in the action path. The study makes the following possible contribution. First, at the theoretical level, this paper explores the driving logic of industrial AI transformation from the perspective of corporate CEOs' academic experience, which provides a new theoretical basis for understanding the strategic decision-making process of industrial AI transformation and

forms a beneficial supplement to the relevant research on economic consequences of CEO's academic experience. Second, from a practical point of view, this paper highlights the value effect of CEOs' academic experience in the process of industrial AI transformation, which is helpful for enterprises to optimize the construction of executive selection and promotion system in the process of industrial AI transformation. Finally, different from the research of single independent company, this paper focuses on the special governance situation of parent-subsidiary companies in the framework of enterprise groups, further deepening the research on the synergy of enterprise groups and providing a more comprehensive analysis perspective for industrial AI transformation.

2. Literature review and hypothesis development

2.1 Literature review

According to the upper echelons theory, enterprise decision-making is essentially the result of environmental factors being filtered and selected by executive's bounded rationality, and the cognitive basis and value orientation of executives are the key factors determining enterprise decision-making (Hambrick and Mason, 1984). From the perspective of psychology and behavioral science, CEO's management skills are not innate, and their professional experience greatly determines their values and behavioral patterns (Benmelech and Frydman, 2015; Schoar and Zuo, 2017). Existing literature has studied the impact of executives' personal experiences such as military experience, disaster experience, overseas experience and financial experience on business management behaviors (Benmelech and Frydman, 2015; Bernile *et al.*, 2017; Yuan and Wen, 2018; Yang *et al.*, 2021). Compared with other professional experiences, academic experience has the characteristics of long-term, rigorous and innovative, which shapes executives' higher moral quality and stronger innovative spirit. The existing literature mainly deals with executives' academic experience and green innovation, profitability, financial reporting quality, IPO discount, and so on (He *et al.*, 2021; Wang *et al.*, 2021; Ma *et al.*, 2019; Zhao *et al.*, 2022). The executives' academic experience reflected in the phenomenon of "literati going to the sea" deserves further attention against the background of the deep integration of AI and the real economy. In the executive team, the CEO is the helmsman of the enterprise and often plays a decisive role in decision-making. Based on this, the impact of scholar-type CEOs on industrial AI transformation is worthy of further exploration.

2.2 Scholar-type CEOs and industrial AI transformation

This paper argues that scholar-type CEOs have the motivation and ability to promote the industrial AI transformation of manufacturing enterprises. On the one hand, from the perspective of decision-making tendencies, the CEO's personality traits shaped by academic experience meet the requirements of industrial AI transformation. First, academic research requires continuous trial and error rather than overnight success, and this process cultivates the CEO's persevering spirit of exploration, courage to fail and responsibility (Ederer and Manso, 2013), CEOs with long-term academic training will analyze problems more rigorously based on their advanced knowledge and skills when making decisions (Jiang and Murphy, 2007), so as to make more proactive, rational and deliberate decisions in favor of industrial AI transformation. Second, scholar-type CEOs with divergent thinking and critical thinking have a stronger ability to perceive and integrate information, are more willing to accept new things and have a higher sensitivity to the frontiers of science and technology (Shen *et al.*, 2020). Moreover, scholar-type CEOs possess independent thinking ability to explore answers from multiple perspectives without hidebound by convention, which can promote the diversification of suggestions and improve the decision-making quality of the executive team (Francis *et al.*, 2015), so as to make reasonable and effective industrial AI transformation

decisions. Finally, the group of "scholars" bears the "feelings of nation and country" of Chinese intellectuals and has a higher moral level and sense of social responsibility (Cho *et al.*, 2017; Zhao *et al.*, 2021), which makes them less likely to have "career worries" and less likely to act short-sightedly due to quick success or risk-averse motives. Therefore, in the face of industrial AI transformation with high uncertainty, scholar-type CEOs are more willing to make forward-looking decisions on industrial AI transformation and upgrading with a long-term vision from the overall interests.

On the other hand, from the perspective of decision implementation, the ability and resources brought by academic experience can promote the industrial AI transformation of enterprises. First, the transformation cycle of industrial AI is long and uncertain, and the process needs to occupy a large amount of enterprise resources. In this case, the upgrading projects of AI technologies are often subject to great risks and challenges (Yang *et al.*, 2018). Scholar-type CEOs can reduce the audit costs by improving the company's accounting information quality and corporate governance level (Francis *et al.*, 2015) and reduce the financing cost of corporate debt by reducing the information risk and debt agency risk (Wang *et al.*, 2021). According to the asymmetric information theory, the less external financing pressure faced by enterprise, the higher the financial flexibility of enterprises (Mikkelson and Partch, 2003). At this time, the greater the risk premium of enterprises investing in AI, which can effectively enhance enterprises' R&D investment in AI projects. Second, the weak market concept of Chinese researchers and the lack of venture capital intervention make the transformation rate of scientific research achievements still at a low level, and a large number of achievements only stay in the "ivory tower." As the invisible relationship bridges connecting universities and enterprises, scholar-type CEOs have social resources of universities and research institutions that give enterprises a first-mover advantage in acquiring transformational resources such as talents, technical equipment and information (Faleye *et al.*, 2014; Yin *et al.*, 2022), which can greatly reduce the transformation cost of university achievements, and provide technical support and necessary hardware configuration for the deep transformation of industrial AI transformation.

Based on the above analysis, the following hypothesis is proposed:

H1. Scholar-type CEOs can promote the industrial AI transformation of manufacturing enterprises.

2.3 The moderating effect of parent-subsidiary corporations executives' ties

As a governance structure with unified coordination and centralized allocation for executives within the framework of the enterprise group, the parent-subsidiary corporations executives' ties mainly refers to a state in which executives, including the board of directors and managers, serve in both the parent company and the subsidiary, which is an important way and arrangement for enterprise groups to gain competitive advantages and improve the efficiency of group operations (Opie *et al.*, 2019; Xu *et al.*, 2021). In this study, it is believed that the parent-subsidiary corporations executives' ties can strengthen the role of scholar-type CEOs in promoting industrial AI transformation through a synergy mechanism. The specific logic is as follows:

First, as an important manifestation of strengthening the power allocation of subsidiary executives, the parent-subsidiary corporations executives' ties has a positive effect on stimulating missionalism and stewardship mentality of subsidiary CEOs (Belenzon *et al.*, 2019; Xu *et al.*, 2019). Scholar-type CEOs can more effectively avoid adverse selection and moral hazard problems by correcting short-sighted behavior and are better able to give full play to their innovative thinking mode to effectively capture the signals of policy changes and gain insight into the future prospects of AI applications, and then more funds will be invested in long-term industrial AI transformation projects (Sheng *et al.*, 2022). Second, in response to the "financing constraint" problem, enterprise groups can give full play to the functions of the internal capital market through the parent-subsidiary corporations executives' ties

(Kabbach-de-Castro *et al.*, 2022), and the scholar-type CEOs under the mechanism of the parent-subsidiary corporations executives' ties have a higher degree of control over social resources, provide more adequate and lasting financial support for the AI projects of listed subsidiaries. The increased financial flexibility of listed subsidiaries is more capable of bearing the high cost of industrial AI transformation and more able to digest the failure of industrial AI transformation, thus increasing the confidence line for the scholar-type CEOs to make forward-looking decisions on transformation and upgrading, and speeding up the transformation process.

Based on the above analysis, the following hypothesis is proposed:

H2. The parent-subsidiary corporations executives' ties positively moderates the impact of scholar-type CEOs on industrial AI transformation.

2.4 The mediating effect of internal control quality

Enterprise internal control is the system construction and implementation of "human" as the main body. The executive team, especially the CEO, bears the main responsibility of building the internal control system and maintaining its effectiveness (Salehi *et al.*, 2021), and CEO's personal characteristics have an important impact on the internal control quality of enterprise (Shen *et al.*, 2021). In this study, it is believed that scholar-type CEOs promote industrial AI transformation by improving internal control quality. The specific logic is as follows.

First, scholar-type CEOs improve the quality of internal control. Scholar-type CEOs have a stronger sense of social responsibility for the enterprise (Cho *et al.*, 2017) and tend to pay more attention to the effectiveness of the design, selection and implementation of the internal control system. In addition, good academic thinking and theoretical cultivation obtained from academic experience enable CEOs to have a more forward-looking vision and stronger risk prevention ability. Therefore, CEO's academic experience is more conducive to the construction and improvement of the internal control system of the enterprise. Second, the high-quality internal control contributes to the promotion of industrial AI transformation. The construction of internal control can curtail the intentional manipulation of accounting information and reduce the inherent risks of business strategies (Hu *et al.*, 2020), which enhances the targeting of funds, ensures that resources can be invested in a long-term and continuous manner, and enables enterprises to form a cyclic chain of transformation and upgrading, thereby promoting the industrial AI transformation of manufacturing enterprises.

Based on the above analysis, the following hypothesis is proposed:

H3. Scholar-type CEOs promotes industrial AI transformation of manufacturing enterprises by improving internal control quality.

2.5 Heterogeneity analysis of property rights nature of enterprise groups

Many previous studies have proved that under the institutional environment of China, the nature of property rights determines a series of corporate structural governance issues, such as the allocation form of enterprise resources, cooperation and control between owners and operators, resulting in great differences in internal governance logic and decision-making mechanisms between state-owned enterprises and private enterprises (Clarke, 2003; Li *et al.*, 2018). Based on this, this paper further subdivides the property rights nature of enterprise groups to study the impact of scholar-type CEOs on industrial AI transformation. The specific logic is as follows.

First, the ownership status of state-owned enterprises gives them inherent advantages in political relations, which makes state-owned enterprises have a more relaxed transition environment and higher tolerance for transition failures. Furthermore, the political connection enable state-owned enterprises to obtain more policy support and resource

inclination (Jian *et al.*, 2020), which ensures the continuous investment of funds in the process of industrial AI transformation, and makes scholar-type CEOs of state-owned enterprises have more decision-making space. To sum up, the soft budget constraint of state-owned enterprises makes scholar-type CEOs more capable and willing to carry out industrial AI transformation. Second, private enterprises are faced with stronger external financing constraints and competitive pressures and have been subject to "ownership discrimination" in terms of public resource allocation and administrative protection for a long time (Bai *et al.*, 2021), which makes private enterprises have a lower tolerance for transformation failure, and CEOs make more cautious and conservative decisions, especially for projects with large capital investment and long payback period. Therefore, the impact of scholar-type CEOs on the industrial AI transformation is suppressed to a certain extent.

Based on the above analysis, the following hypothesis is proposed:

H4. Compared with private enterprises, scholar-type CEOs play a stronger role in promoting industrial AI transformation of state-owned enterprises.

3. Methodology and variable definitions

3.1 Sample selection and data source

First, as it is difficult to obtain public information for nonlisted firms in China, this paper preliminarily selects A-share manufacturing listed companies in Shanghai Stock Exchange and Shenzhen Stock Exchange from 2014 to 2020 as the research object by referring to the company control chain diagram and annual report. Second, Chinese enterprise groups are major players in the national economy, manufacturing firms face high technology and market uncertainty, and market competition is extremely fierce. Chinese firms have strong incentives to engage in industrial AI transformation through enterprise groups. Therefore, this paper further selects listed subsidiaries of enterprise groups as initial samples. Drawing on the practice of existing research, this paper adopts the following criteria for sample selection: (1) exclude financial listed companies; (2) exclude ST, *ST and listed companies that were delisted during the observation period; (3) eliminate listed companies with missing main variables. In order to eliminate the influence of extreme values, all continuous variables are processed by Winsorize at 1 and 99% levels, and 4722 observation samples are finally obtained. The industrial AI transformation data is collected manually from annual reports of listed companies for the period 2014–2020, and other main variables and control variables are derived from the China Stock Market and Accounting Research (CSMAR), which contains detailed information on firms listed on the Shanghai and Shenzhen Stock Exchange and has been used extensively by past scholars (e.g. see Zhao *et al.*, 2022; Shen *et al.*, 2020).

3.2 Variable definitions

3.2.1 Industrial AI transformation (INM). The measuring method of industrial AI transformation is shown in Figure 1. This paper adopts the double difference method (DID) to construct the measurement index AI_{it}*$YEAR_{it}$. Firstly, the dummy variable AI_{it} is constructed, indicating whether company i has undergone industrial AI transformation, and the industrial AI transformation enterprise is 1, otherwise, it is assigned to 0. Then, the dummy variable $YEAR_{it}$ is constructed to indicate the year that i company has undergone industrial AI transformation, and the implementation year is 1, otherwise it is 0. The specific steps are as follows. Firstly, manually collect the annual reports of all sample companies from 2014 to 2020, select words such as "intelligence", "automation", "wisdom" and "informatization" that reflect the transformation of industrial AI, and filter out all the statements containing keywords; Second, based on the connotation of industrial AI

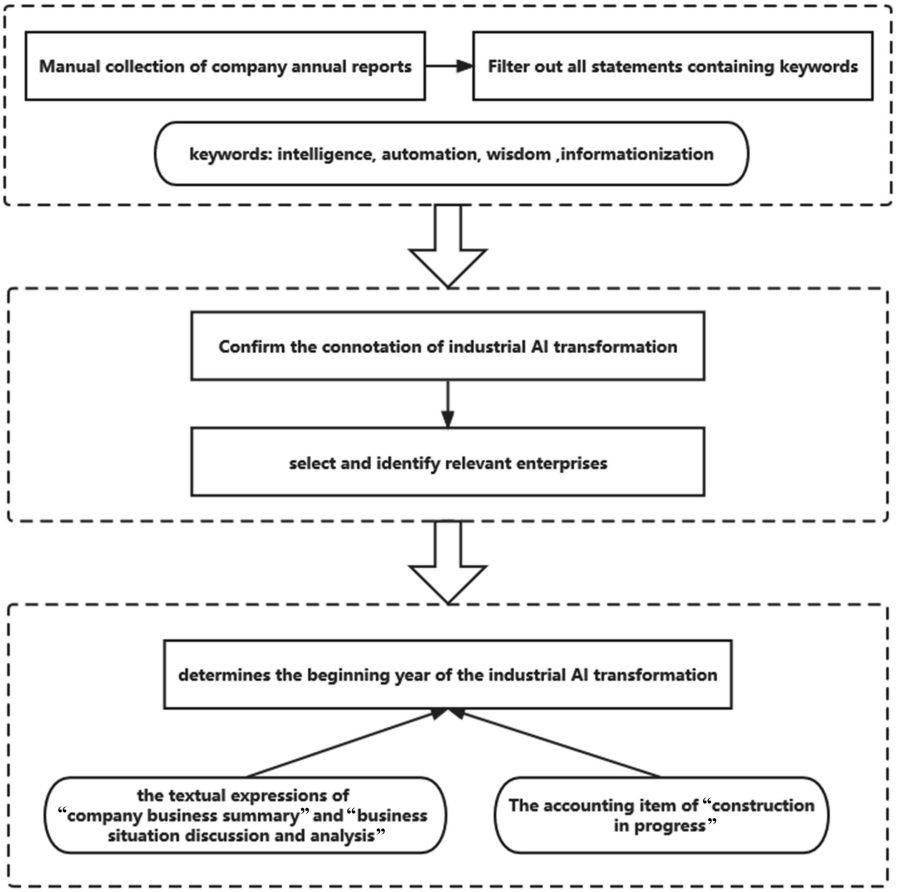

Figure 1.
The measuring method of industrial AI transformation

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transformation, enterprises that are in line with the deep integration of the new generation of information technology and manufacturing industry are selected and identified as industrial AI transformation enterprises, with AI_{it} as 1; Finally, this paper manually determines the beginning year of the industrial AI transformation from the following two aspects: (1) The year in which the enterprise applied AI products is involved in the textual expressions of "company business summary" and "business situation discussion and analysis". For example, Shenzhen Zhongheng Huafa Co., Ltd. has updated some old injection molding machine equipment in 2014, and the energy-saving effect has continued to appear. In addition, with the implementation of automation improvement and process optimization process, the waste of manpower input and production materials has greatly reduced, and the production efficiency has been significantly improved; (2) the accounting item of "construction in progress" refers to the year when the project applied by "AI" has been completed and has reached the expected state of use. For example, Shenzhen Danbang Technology Co., Ltd. completed the project of intelligent monitoring system for the whole process of sewage discharge in 2020 and started operation. Finally, the measurement index AI_{it}*$YEAR_{it}$ of industrial AI transformation variables is obtained.

3.2.2 Scholar-type CEOs (ACADE). Reference to the research of Zhao *et al.* (2022) and Wang *et al.* (2021), this paper adopts the method of designing dummy variables to assign a value of 1 for CEO with academic experience and 0 otherwise. The specific criteria are as follows: (1) once taught in university; (2) once worked in public research institutions; (3) once engaged in research in academic associations. Those who meet at least one of the above criteria are judged as scholar-type CEOs.

3.2.3 Parent-subsidiary corporations executives' ties (ET). Refers to the measurement method of Xu *et al.* (2021), this paper adopts the ratio of the number of subsidiary executives concurrently serving as executives in the parent company to the total number of subsidiary executives to measure the degree of executive connection between the parent and subsidiary. Further, grouped by the "year-industry" mean of ratio, with the value of 1 for those above the mean and 0 otherwise. It should be noted that the scope of "executives" in this study is defined based on a broad concept, including the company's board members, general managers, deputy general managers, chief financial officers, board secretaries and other managers specified in the company's articles of association.

3.2.4 Internal control quality (IC). Referring to the research of Li *et al.* (2021), this paper selects the Dibo China Listed Company Internal Control Index as the proxy index of the internal control quality of listed companies, and the index is divided by 100 to standardize, with a higher value of the index representing higher internal control quality.

3.2.5 Property rights nature of enterprise groups (STATE). Listed companies belonging to state-owned enterprise groups are assigned to 1 and those belonging to private enterprise groups are assigned to 0.

3.2.6 Control variables. Referring to previous studies, this paper controls the following in regression analysis: the ownership concentration (TOP1), the asset-liability ratio (LEV), the board size (BOD), the proportion of independent directors (INDE), the company size (SIZE), operating CASH flow (CASH), the Tobin *Q* value (TOBIN), CEO gender (GENDER), CEO age (AGE) and the board leadership structure (DUALITY). In addition, the fixed effect of year is controlled. The definition and measurement of variables are shown in Table 1.

3.3 Models

To test the hypotheses of this paper, the following regression models are designed for this study. Model (1) is used to test the effect of scholar-type CEOs on industrial AI transformation, and model (2) is used to test the moderating role of the parent-subsidiary corporations executives' ties between scholar-type CEOs and industrial AI transformation. Model (3) and model (4) are used to test the mediating role of internal control quality between scholar-type CEOs and industrial AI transformation. Model (5) and model (6) are grouped based on the nature of property rights of enterprise groups.

$$\text{Model1}: INM = \alpha_0 + \alpha_1 ACADE + Controls + \sum YEAR + \varepsilon$$

$$\text{Model2}: INM = \alpha_0 + \alpha_1 ACADE + \alpha_2 ET + \alpha_3 ACADE * ET + Controls + \sum YEAR + \varepsilon$$

$$\text{Model3}: IC = \alpha_0 + \alpha_1 ACADE + Controls + \sum YEAR + \varepsilon$$

$$\text{Model4}: INM = \alpha_0 + \alpha_1 IC + \alpha_1 ACADE + Controls + \sum YEAR + \varepsilon$$

$$\text{Model5}: INM = \alpha_0 + \alpha_1 ACADE + Controls + \sum YEAR + \varepsilon(STATE = 1)$$

$$\text{Model6}: INM = \alpha_0 + \alpha_1 ACADE + Controls + \sum YEAR + \varepsilon(STATE = 0)$$

Code	Variables	Index
INM	Industrial AI transformation	Indicates whether the enterprise has undergone industrial AI transformation.See the formula above for the specific measurement method
ACADE	Scholar-type CEOs	The CEO with academic experience is assigned as "1"; Otherwise, "0"
ET	Parent-subsidiary corporations executives' ties	Grouped by the "year-industry" mean of ratio, with the value of "1" for those above the mean and "0" otherwise
IC	Internal control quality	The Dibo China listed company internal control index
STATE	Property rights nature of enterprise groups	Listed companies belonging to state-owned enterprise groups are assigned to "1" and those belonging to private enterprise groups are assigned to "0"
TOP1	The shareholding ratio of the largest shareholder	The proportion of shares held by the largest shareholder of the listed company to the total share capital
LEV	The asset-liability ratio	The year-end asset-liability ratio of listed companies
BOD	The board size	The number of board members of listed companies
INDE	The proportion of independent directors	The proportion of independent directors to the total board of directors of listed companies
SIZE	The company size	The natural logarithm of the total assets of the listed company at the end of the year
CASH	Operating cash flow	The ratio of annual net operating cash flow of listed companies to total assets at the end of the period
TOBIN	The TOBIN *Q* value	The ratio of the market value of listed companies to total assets at the end of the year
GENDER	CEO gender	If the CEO is male, assign the value "1"; otherwise, "0"
AGE	CEO age	The natural logarithm of CEO's age
DUALITY	The board leadership structure	If the chairman and general manager of a listed company hold both positions, take "1", otherwise take "0"
YEAR	Year	Dummy variable, the year of the observation sample belongs to this year and is recorded as "1", otherwise it is "0"

Table 1.
Variable definitions

Source(s): Author's own creation/work

Among them, *ACADE***ET* denotes the interaction term of scholar-type CEOs and the parent-subsidiary corporations executives' ties, *Controls* is the control variable described previously; α_0 is the intercept term; ε represents the error disturbance term, and α represents the regression coefficient of the explanatory variables.

4. Data analysis and results discussion

4.1 Descriptive statistics

Descriptive statistics of all variables are depicted in Table 2. It can be seen that the mean and standard deviation of industrial AI transformation (INM) are 0.468 and 0.499, indicating that there are still many listed subsidiaries have not yet carried out industrial AI transformation. The average value of scholar-type CEOs (ACADE) is 0.140, which indicates that approximately 14% of CEOs of Chinese manufacturing companies have academic background. It shows that scholar-type CEOs is representative in the management team, and it has a strong realistic foundation to study the influence of CEO's academic experience on industrial AI transformation decision-making; the standard deviation of the company size (SIZE) is 1.205, indicating that there is a large difference in the scale of listed subsidiaries. In addition, the descriptive statistical results of the remaining control variables are consistent with existing research literature and will not be repeated here.

Variables	Variable	Minimum	Median	Maximum	Mean	Standard deviation
INM	4722	0.000	0.000	1.000	0.468	0.499
ACADE	4722	0.000	0.000	1.000	0.140	0.347
ET	4722	0	0	1	0.454	0.498
IC	4722	0	6.608	8.208	6.343	1.348
STATE	4722	0	0	1	8.208	0.500
TOP1	4722	0.051	0.341	0.900	0.357	0.137
LEV	4722	0.076	0.436	0.908	0.442	0.187
BOD	4722	5.000	9.000	14.000	8.756	1.540
INDE	4722	0.333	0.333	0.571	0.370	0.052
SIZE	4722	20.237	22.540	26.026	22.652	1.205
CASH	4722	−0.123	0.044	0.219	0.048	0.060
TOBIN	4722	0.837	1.655	7.999	2.077	1.283
GENDER	4722	0.000	1.000	1.000	0.946	0.226
AGE	4722	3.434	3.892	4.159	3.862	0.135
DUALITY	4722	0.000	0.000	1.000	0.190	0.392

Source(s): Author's own creation/work

Table 2.
Descriptive statistics

4.2 Correlation analysis

Table 3 reports the results of the correlation analysis among all variables in this paper. It can be seen from Table 3 that the correlation coefficient between ACADE and INM is 0.024, which is significant at the 10% level, indicating that there is a significant positive relationship between the scholar-type CEOs (ACADE) and the industrial AI transformation (INM) of manufacturing enterprises' relationship, which preliminarily verified hypothesis H1. The correlation coefficient between SIZE and INM is 0.194, which is significant at the 1% level, indicating that the larger the scale of the listed subsidiary, the more likely it is to carry out industrial AI transformation. In addition, according to the correlation analysis results in Table 3, except for −0.551, the correlation coefficients between other variables are all between plus and minus 0.5, indicating that the selection of variables is reasonable, and there is no serious multicollinearity in the regression model, so the regression analysis of causality among variables can be carried out.

4.3 Multiple regression results

To verify the hypotheses proposed above of this paper, it is tested by stata15.0 software. Column (1) in Table 4 shows the regression analysis result without control variables. It can be seen that the regression coefficient of the scholar-type CEOs (ACADE) is 0.284, which is significant at the 1% level; the results of column (2) in Table 4 after adding control variables show that the regression coefficient of scholar-type CEOs (ACADE) is 0.263, which is significant at the 1% level. All the above results show that scholar-type CEOs have a significant positive relationship with industrial AI transformation. The hypothesis H1 has been verified.

The analysis results of the moderating effect of parent-subsidiary corporations executives' ties on the relationship between scholar-type CEOs and industrial AI transformation are shown in column (3) and column (4) of Table 4. It can be found that the regression coefficient of scholar-type CEOs does not pass the significance test when the degree of parent-subsidiary corporations executives' ties is lower and is significantly positive at the 1% level when the degree of parent-subsidiary corporations executives' ties is higher. The regression result shows that parent-subsidiary corporations executives' ties strengthens the positive effect of scholar-type CEOs on industrial AI transformation. The hypothesis H2 can be verified.

The column (5) and column (6) of Table 4 reports the results of internal control quality as an intermediary mechanism. According to the regression results of model (3), it can be seen

Table 3.
Correlation analysis

Variables	*INM*	*ACADE*	*ET*	*IC*	*STATE*	*TOP1*	*LEV*	*BOD*	*INDE*	*SIZE*	*CASH*	*TOBIN*	*GENDER*	*AGE*	*DUALITY*
INM	1.000														
ACADE	0.024*	1.000													
ET	0.002	0.003	1.000												
IC	0.074***	0.022	0.031**	1.000											
STATE	−0.022	−0.162***	0.097***	0.040***	1.000										
TOP1	−0.002	−0.016	0.205***	0.147***	0.063***	1.000									
LEV	0.072***	−0.033**	0.090***	−0.004	0.198***	0.014	1.000								
BOD	−0.003	−0.045***	0.092***	0.044***	0.204***	−0.014	0.117***	1.000							
INDE	0.046***	0.018	−0.077***	−0.004	−0.010	0.039***	0.013	−0.483***	1.000						
SIZE	0.194***	−0.046***	0.089***	0.226***	0.205***	0.142***	0.474***	0.219***	0.057***	1.000					
CASH	0.067***	0.026*	0.077***	0.146***	−0.034**	0.148***	−0.154***	0.036**	0.000	0.114***	1.000				
TOBIN	−0.164**	0.102***	−0.068***	0.018	−0.188***	0.006	−0.391**	−0.096**	−0.019	−0.551**	0.072**	1.000			
GENDER	−0.025*	0.001	0.076***	−0.010	0.075***	0.021	0.050***	0.107***	−0.105***	−0.002	−0.004	−0.017	1.000		
AGE	−0.018	0.102***	0.006	0.016	0.100***	0.041***	0.035**	0.027*	0.047***	0.061***	0.013	−0.002	0.006	1.000	
DUALITY	0.047**	0.161**	−0.078***	−0.008	−0.272***	−0.033*	−0.061**	−0.155**	0.083***	−0.102**	0.015	0.082**	−0.030**	0.157**	1.000

Note(s): *** means $p < 0.01$, ** means $p < 0.05$, * means $p < 0.1$
Source(s): Author's own creation/work

Table 4. Multiple regression analysis results

Variables	(1) *INM*	(2) *INM*	(3) *INM*	(4) *INM*	(5) *IC*	(6) *INM*	(7) *INM*	(8) *INM*
ACADE	0.284***	0.263***	0.362***	0.191	0.162***	0.249***	0.538***	0.063
	(3.20)	(2.87)	(2.64)	(1.53)	(2.92)	(2.72)	(3.19)	(0.57)
IC						0.094***		
						(3.76)		
TOP1		−0.014	−0.763**	0.501	0.666***	−0.079	−0.185	0.113
		(−0.06)	(−2.06)	(1.53)	(4.62)	(−0.33)	(−0.52)	(0.34)
LEV		−0.004	−0.737**	0.543**	−1.283***	0.109	0.597**	−0.444
		(−0.02)	(−2.44)	(2.06)	(−10.86)	(0.55)	(2.10)	(−1.57)
BOD		0.019	−0.030	0.060*	−0.011	0.020	0.078**	−0.034
		(0.82)	(−0.82)	(1.88)	(−0.73)	(0.86)	(2.43)	(−0.87)
INDE		1.265*	1.794*	0.964	−0.904**	1.360**	1.595*	0.934
		(1.88)	(1.72)	(1.08)	(−2.22)	(2.02)	(1.75)	(0.88)
SIZE		0.248***	0.387***	0.145***	0.289***	0.222***	0.194***	0.305***
		(7.15)	(7.25)	(3.10)	(13.91)	(6.28)	(4.04)	(5.74)
CASH		1.212**	0.392	1.931**	0.825**	1.154**	−0.467	2.773***
		(2.19)	(0.47)	(2.57)	(2.46)	(2.08)	(−0.57)	(3.58)
TOBIN		−0.057*	−0.044	−0.068*	0.024	−0.061**	−0.055	−0.088**
		(−1.90)	(−0.89)	(−1.76)	(1.33)	(−2.00)	(−1.19)	(−2.12)
GENHDER		−0.133	0.186	−0.294*	−0.052	−0.130	−0.261	−0.017
		(−0.95)	(0.73)	(−1.75)	(−0.61)	(−0.93)	(−1.06)	(−0.10)
AGE		−0.059	0.046	−0.084	−0.009	−0.057	1.165***	−0.309
		(−0.25)	(0.13)	(−0.26)	(−0.06)	(−0.24)	(2.58)	(−1.06)
DUALITY		0.374***	0.269**	0.448***	0.113**	0.364***	0.308*	0.353***
		(4.53)	(2.05)	(4.16)	(2.26)	(4.40)	(1.83)	(3.54)
YEAR	YES	YES	YES	YES	YES	YES	YES	YES
Constant term	−1.295***	−7.140***	−10.074***	−5.303***	0.651	−7.236***	−11.650***	−6.628***
	(−13.78)	(−6.21)	(−5.81)	(−3.38)	(0.94)	(−6.29)	(−6.09)	(−3.91)
N	4722	4722	2144	2578	4722	4722	2302	2420
R^2	0.072	0.094	0.107	0.092	0.074	0.096	0.122	0.085
F	469.46	614.91	316.87	326.49	23.21	629.45	387.46	284.38

Note(s): *** means $p < 0.01$, ** means $p < 0.05$, * means $p < 0.1$; The value of t is in parentheses
Source(s): Author's own creation/work

that the scholar-type CEOs (ACADE) is significantly positively correlated with internal control quality (IC) at the 1% level, indicating that the scholar-type CEO improves the internal control quality of listed subsidiaries. According the regression results of model (4), it can be seen that the regression results of scholar-type CEOs (ACADE) is significantly positive. In addition, the regression result of internal control quality (IC) is significant at the 1% level, which means that internal control quality has a positive impact on the industrial AI transformation of enterprises. The above results show that internal control quality plays a significant partial mediating role between scholar-type CEOs and industrial AI transformation, which is in line with the assumption of this paper.

The analysis results of the moderating effect of property rights nature of enterprise groups on the relationship between CEO's academic experience and industrial AI transformation are shown in column (7) and column (8) of Table 4. It can be found that the regression coefficient of scholar-type CEOs does not pass the significance test in private companies and is significantly positive at the 1% level in state-owned companies. It indicates that compared with private enterprises, the promotion effect of scholar-type CEOs on industrial AI transformation is stronger in state-owned enterprises, which is consistent with the logic of the previous hypothesis.

5. Robustness

5.1 Instrumental variable method

In order to avoid the endogeneity problems caused by missing variables, this paper uses instrumental variables for two-stage least squares (2SLS) regression analysis. According to the research in this paper, the suitable instrumental variables need to meet the following two conditions: (1) they are related to the appointment decision of CEO; (2) it has not related to industrial AI transformation. Taking two aspects into consideration, this paper uses the natural logarithm (IV_ACADE) of the number of colleges and universities in the province where the company is registered in the current year as an instrumental variable. The basic reasons for choosing this instrumental variable are as follows: On the one hand, the number of colleges and universities in the area where listed companies are located indicates that the local academic culture is strong, and the ability and quality of the academic group are more respected and valued, and they are more inclined to hire CEOs with academic experience to preside over the company's operation; on the other hand, the number of ordinary colleges and universities reflects the local education level, and there is no direct correlation with corporate decisions (including industrial AI transformation decisions).

The empirical results of two-stage regression (2SLS) are shown in column (1) and column (2) of Table 5. From column (1) of Tables 5, it can be seen that in the first stage of regression, IV_ACADE and ACADE are significantly positively correlated at the 5% level, indicating that listed companies in areas with a strong academic atmosphere are more willing to hire scholar-type CEOs, which is in line with the previous hypothesis. It can be seen from column (2) that in the second-stage regression, ACADE is significantly positive at the 10% level, indicating that after controlling for endogeneity problems such as potential omitted variables, the conclusions of this study are basically unchanged.

5.2 Propensity score matching

Considering the problem of sample self-selection, this paper uses the propensity score matching method (PSM) to perform 1:1 proximity matching on the sample of companies undergoing industrial AI transformation. The model variables for calculating the propensity score include TOP1, LEV, BOD, INDE, SIZE, CASH, DUALITY, and the Logit model is used for regression analysis of the matched sample data. Column (3) in Table 5 reports the

Variables	(1) *ACADE*	(2) *INM*	(3) *INM*	(4) *INM*	(5) *INM*	(6) *INM*
ACADE		1.339*	0.307**			0.161***
		(1.72)	(2.22)			(2.87)
IV_ACADE	0.027**					
	(2.41)					
L.ACADE				0.279***		
				(2.84)		
L2.ACADE					0.284***	
					(2.71)	
TOP1	−0.026	0.036	−0.171	0.043	0.020	−0.013
	(−0.68)	(0.48)	(−0.39)	(0.16)	(0.07)	(−0.09)
LEV	−0.022	0.031	−0.122	0.152	0.330	−0.003
	(−0.70)	(0.50)	(−0.30)	(0.70)	(1.37)	(−0.03)
BOD	−0.004	0.010	−0.041	0.025	0.044	0.013
	(−1.04)	(1.26)	(−0.98)	(0.94)	(1.51)	(0.88)
INDE	−0.060	0.381*	1.560	1.372*	1.809**	0.791*
	(−0.56)	(1.82)	(1.27)	(1.87)	(2.25)	(1.93)
SIZE	−0.000	0.054***	0.441***	0.233***	0.227***	0.152***
	(−0.00)	(5.25)	(6.41)	(6.15)	(5.52)	(7.22)
CASH	0.085	0.141	0.828	1.881***	2.507***	0.708**
	(0.97)	(0.78)	(0.76)	(3.09)	(3.66)	(2.10)
TOBIN	0.012**	−0.026**		−0.075**	−0.117***	−0.034*
	(2.49)	(−2.08)		(−2.29)	(−3.14)	(−1.85)
GENDER	0.005	−0.037		−0.039	−0.053	−0.083
	(0.24)	(−0.88)		(−0.25)	(−0.32)	(−0.98)
AGE	0.209***	−0.274		−0.021	0.160	−0.036
	(5.54)	(−1.57)		(−0.08)	(0.57)	(−0.25)
DUALITY	0.125***	−0.080	0.087	0.359***	0.241**	0.230***
	(9.61)	(−0.79)	(0.49)	(3.94)	(2.42)	(4.60)
YEAR	YES	YES	YES	YES	YES	YES
Constant term	−0.750***	−0.267	−11.225***	−6.813***	−7.209***	−4.377***
	(−4.00)	(−0.45)	(−7.74)	(−5.42)	(−5.29)	(−6.28)
N	4722	4722	1320	3779	3136	4722
R^2	0.042	–	0.098	0.072	0.059	0.094
F	12.21	354.16	178.69	379.06	255.11	614.69

Note(s): *** means $p < 0.01$, ** means $p < 0.05$, * means $p < 0.1$; The value of t is in parentheses
Source(s): Author's own creation/work

Table 5.
Robustness

regression results. The regression coefficient of scholar-type CEOs (ACADE) is 0.307, which is significant at the 5% level. The results are consistent with the previous results, indicating that the research conclusion of this paper is still robust after considering the related endogenous issues.

5.3 Other robustness checks

In order to ensure the reliability of the research conclusions, we also conducted the following robustness tests: (1): The exploration process and achievement of industrial AI transformation is relatively long, and scholar-type CEOs conducting industrial AI transformation are likely to reap the fruits of predecessors. In order to avoid the endogeneity bias caused by "the predecessors plant the trees, the later generations enjoy the shade," this paper treats the dependent variables with one lag period and two lag periods respectively and uses the Logit model to estimate. Column (4) and (5) in Table 5 report the regression results, which are still consistent with our assumptions. (2) Change the test model

for the impact of scholar-type CEOs on industrial AI transformation, and re-test it with the help of the Probit model. The column (6) in Table 5 shows the specific regression results, which are consistent with the above conclusions.

6. Conclusion and implications

6.1 Conclusion

"Literati goes to sea" is a unique phenomenon in China's economic development, and the academic experience of executives may affect the management decisions of enterprises. As the industrial AI transformation has gradually attracted the attention of the theoretical and practical circles, this paper empirically tests the impact of scholar-type CEOs on industrial AI transformation of manufacturing enterprises based on the upper echelons theory. The following conclusions are drawn: Scholar-type CEOs can significantly promote the industrial AI transformation of manufacturing companies, which indicates that the CEO shaped by academic research experience not only meets the requirements of industrial AI transformation, but also relies on the rich resources brought by academic experience, which can significantly improve the level of industrial AI transformation of enterprises as a whole. The parent-subsidiary corporations executives' ties can play an effective synergistic effect and strengthen the positive impact of scholar-type CEOs on industrial AI transformation. On this basis, we also find that the internal control quality plays a partial mediating role between scholar-type CEOs and industrial AI transformation; compared with private enterprise groups, the promoting effect of CEO's academic experience on industrial AI transformation is stronger in state-owned enterprise groups.

6.2 Theoretical implications

Based on the above research findings, the following theoretical implications are obtained: First, this paper expands the research related to the influencing factors of industrial AI transformation based on upper echelons theory, and clarifies the influencing mechanism of scholar-type CEOs affecting industrial AI transformation from the perspective of executives' behavior. This paper adopts a manual collection method to organize industrial AI transformation data, responding to the call to explore the relationship between AI and strategic transformation of manufacturing companies (Burstrm *et al.*, 2021), and provides theoretical support and new solution ideas at the micro level for reexamining and solving problems in the process of industrial AI transformation in China's manufacturing. Second, previous studies have mainly explored the effects of scholar-type CEOs on green innovation, profitability and firm value, IPO discount (He *et al.*, 2021; Wang *et al.*, 2021; Zhao *et al.*, 2022), and few scholars have explored the relationship between scholar-type CEOs and industrial AI transformation. Our study further enriches the research framework on the economic consequences of scholar-type CEOs, and provides a useful supplement to the research literature in the field of upper echelons theory. Third, taking the parent-subsidiary corporations executives' ties as the entry point, this paper is not limited to a single enterprise but involves the management practice of resource allocation within the enterprise groups, further clarifies the internal logic of the decision-making of industrial AI transformation of listed companies within the framework of enterprise groups, providing theoretical reference for the scientific design of the governance mechanism of parent-subsidiary companies.

6.3 Practical implications

The study's practical implications are discussed below. First, scholar-type CEOs have higher digital and intelligent literacy and are active drivers of industrial AI transformation of enterprises. Enterprises should optimize the construction of executive selection and

promotion system under the implementation system of industrial AI transformation strategy, increase the proportion of academic human capital in the executive team when selecting talents, and give full play to the unique advantages of academic talents, so as to realize the transformation and upgrading of industrial AI with better efficiency and higher quality. Moreover, the parent-subsidiary system is the most widely used organizational form of Chinese enterprise groups in practice. It is necessary for subsidiaries to give full play to the synergy advantages of enterprise groups by means of parent-subsidiary corporation's executives ties and other means, and rely on the internal capital market to provide alternatives, and obtain more and longer lasting financial support, thereby laying a solid resource foundation for industrial AI transformation.

Second, government departments should formulate policies on encouraging universities and researchers to enter state-owned enterprises base on industrial AI transformation, so as to more fully mobilize and coordinate university-enterprise resources, and vigorously promote the reform of talent development system and mechanism. In addition, the government should accelerate the construction of policy system design for different types of industrial AI transformation, and create a group of professional managers of SOEs in the true sense by selecting and hiring scholarly executives to provide empowering effects for the construction and optimization of the internal control system of Chinese enterprises, so as to better meet and embrace industrial AI transformation.

6.4 Limitations and future directions

Several limitations should be noted and addressed in future research. First, the research samples of this paper are listed manufacturing companies in Shanghai Stock Exchange and Shenzhen Stock Exchange which are affiliated to enterprise groups, and whether the relevant conclusions are applicable to the SME Board and Growth Enterprise Market requires further research in the future. Second, due to the limitation of executive information disclosure, this paper lacks in-depth analysis of CEO's tenure in universities or research institutions, specific positions and research fields, which may be closely related to CEO's academic ability, social resources and relationship network. Therefore, the impact of differentiation of academic experience on industrial AI transformation needs to be further studied in the future.

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