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Can state ownership help facilitate the digital transformation of private sector enterprises? Evidence from China

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This study investigates the role of state ownership in driving the digital transformation of private sector enterprises (PSEs) in China, using data from A-share listed firms between 2012 and 2022. Digital transformation is critical for PSEs to maintain competitiveness in an increasingly technology-driven economy, and state ownership provides unique resources and strategic support to achieve this. Our analysis reveals that state ownership enhances PSEs' adoption of innovative technologies, with its impact varying by investor type. When acting as a strategic investor, state ownership significantly facilitates digital transformation, whereas its role as a financial investor has a more limited effect. This influence is stronger in cities with favorable business environments and in emerging industries. Furthermore, state ownership helps mitigate risks from policy uncertainty and boosts innovation outputs, ultimately driving greater digital transformation. These findings underscore the strategic importance of state ownership in fostering technological advancement and resilience in PSEs.

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Introduction

According to the Digital China Development Report 2022, China's digital economy surged in size to 45.5 trillion Yuan during 2021, constituting 39.8% of the country's GDP. This transformation established the digital economy as a significant driving factor behind China's overall economic advancement (Ma and Lin, 2023, Zhang et al. 2024). The private sector enterprises (PSEs) in China have witnessed a swift expansion in recent years. They now constitute 90% of the nation's businesses, contributing over 50% of its tax revenue, driving 60% of its GDP, fostering 70% of its technological innovation, and accounting for 80% of its employment opportunities¹. The ability of PSEs to effectively implement digital transformation is important for the long-term development of China's digital economy. Meanwhile, Petani et al. (2023) highlight that digital transformation is essential for ensuring organizational survival and achieving business success. However, digital transformation often entails high capital investment, technical difficulties, and a long return period (Liu et al. 2022; Xu and Tan, 2024, Eller et al. 2023, and Fan et al. 2024). Compared with state-owned enterprises (SOEs), PSEs in China frequently lack sufficient economic resources to assist with their digital transformation because of ownership discrimination. In this case, PSEs usually seek out alternative mechanisms to make up for their lack of competitiveness. Existing research generally indicates that a firm's political connections with the government allow it to obtain many economic resources, including obtaining resources normally only available to SOEs (Cheng and Wu, 2019).

As for political connections with PSEs, state ownership is a corporate-level connection mechanism and a long-term and stable "symbiotic relationship" established between firms and the government in the form of legal provisions. This can play a more impactful role than entrepreneurial participation in politics (Song et al. 2017). Since the initiation of China's reform and opening-up policy, state ownership within PSEs has manifested in the following scenarios: (1) During the privatization of SOEs, a specific portion of state ownership is retained in the enterprise to maintain its influence; (2) In some resource-poor regions, local governments choose to control local PSEs through state ownership to control resources; and (3) Aligned with the "mixed ownership reform" strategy, the government proactively introduces state ownership into certain PSEs.

At present, existing research shows that the role of state ownership in PSEs includes resource provision and corporate governance. State resource provision means that PSEs can obtain a certain status and treatment similar to those of SOEs, thus taking advantage of external financing and government support (Song et al. 2015). The state governance function means that the state creates effective supervision and a balance system within the PSEs through an equity mechanism by which they serve to curb the actions of private-controlling shareholders and enhance the standard of corporate governance (Li et al. 2023).

PSEs constitute a vital component of China's market economy. Amid China's robust governmental efforts for advancing its digital economy, no study has examined whether state ownership in PSEs assists in their digital transformation. This study aims to fill this gap by examining the impact of state ownership on the digital transformation of PSEs in China. Therefore, using the data of PSEs listed as A-shares on the Shenzhen and Shanghai exchanges from 2012 to 2022, we examine the impact of state ownership on the digital transformation of PSEs. The empirical results show that state ownership can significantly help the digital transformation of PSEs. After classifying state ownership among PSEs, when state ownership functions as a strategic investor, it helps facilitate digital transformation. Contrastingly, when state ownership plays the role of a financial investor, digital

transformation becomes limited. Moreover, state ownership plays a prominent role in facilitating the digital transformation of PSEs in cities with more thriving business environments. Subsequent examinations revealed that, despite the unfavorable impact of macroeconomic policy uncertainties on the digital transformation of PSEs, state ownership can effectively mitigate these detrimental effects. Simultaneously, particularly within emerging industries, state ownership plays a more pronounced role in expediting digital transformation, and PSEs with state ownership significantly enhance their innovation output due to the accelerated pace of their digital transformation.

This paper provides novel insights into the role of state ownership in facilitating the digital transformation of PSEs in China. It makes several key contributions to the literature on corporate governance, digital transformation, and state ownership: (1) The study enriches the theoretical framework on state ownership by indicating it as a key mechanism to provide resources and improve governance in PSEs. It highlights that state ownership can help PSEs overcome financial and technical constraints, making it easier for them to use digital technologies and compete in the digital economy. (2) In contrast to existing research, this paper distinguishes state ownership to two types: strategic investors and financial investors. The results show that strategic investors help more with digital transformation, while financial investors have less of an effect. This gives a clearer idea of how ownership affects company strategies. (3) Additionally, the study takes into account external factors such as the business environment, economic policy uncertainty, and industry attributes within the firm's locality to assess the influence of state ownership on the digital transformation of PSEs.

By addressing these gaps, this study provides important insights for policymakers and businesses to advance digital transformation. Firstly, state ownership helps stabilize enterprises during times of policy uncertainty. Policymakers can use it as a tool to provide resources and improve governance. By doing this, they can guide corporate strategies to align with national development goals. This will help promote digital transformation and long-term economic growth. Secondly, the findings show that state ownership supports innovation, especially in emerging industries. Policymakers should focus on these industries because they need more technological progress and adaptation to changing markets. Using state ownership in these areas can help build stronger foundations for innovation and competitiveness. Lastly, the study suggests improving the business environment and reducing policy risks. Policymakers should create better conditions for enterprises to benefit from state ownership. At the same time, companies should adjust their shareholder structures so that state-owned investors become strategic partners rather than passive participants. This approach will enhance governance and resource use, which can speed up digital transformation and support the growth of the digital economy.

This study offers novel insights into the role of state ownership in facilitating the digital transformation of PSEs, addressing a key research gap and providing actionable recommendations for both policymakers and businesses. Through its findings, this paper contributes to the broader literature on the digital economy, corporate governance, and the intersection of state and private sector collaboration in China's economic development.

Theoretical analysis and research hypothesis

State ownership and digital transformation of PSEs. State ownership plays an important role in the digital transformation of PSEs. The government has closer and more direct connections

with SOEs, but its influence on PSEs through state ownership is becoming more important (Cao et al. 2019). Digital transformation is now a key strategy around the world. Through state ownership, the government can provide policies and resources to PSEs, which helps them improve their ability to achieve digital transformation.

Ren et al. (2019) argue that state ownership helps PSEs allocate resources more effectively. This is important because digital transformation requires significant financial investment (Matt et al. 2015, Lazić et al. 2023, Batrancea et al. 2009, and Zhao et al. 2024). PSEs often face difficulties in accessing resources due to ownership discrimination. With state ownership, PSEs can gain a status similar to SOEs. This allows them to access loans, subsidies, and other financial resources needed for transformation (Maung et al. 2016, Salamzadeh et al. 2024).

State ownership also acts as a political connection. This connection allows PSEs to work with government institutions and research organizations. These partnerships can help solve technical problems, such as shortages of skilled workers and advanced equipment, which are common in PSEs (Yu et al. 2022a).

In terms of governance, state ownership plays a supervisory role (Yu et al., 2022b, Li et al. 2015). State ownership can serve as a mechanism to restrain shareholders from making decisions that may hinder the enterprise's long-term development, given their dominant position. In cases where certain PSEs show reluctance to undergo digital transformation, the government can also utilize the approach of "share withdrawal" to exert influence on the enterprise. In addition, because digital transformation is a high-risk and systematic project (Chen, 2023), PSEs with state ownership need not worry about the bankruptcy risk caused by the failure of the transformation. Thus, this guaranteed system can form a strong risk-bearing capacity for the enterprise (Ding et al. 2021), enhancing its willingness to transform. Therefore, we formulate the following hypothesis:

Hypothesis 1: *State ownership plays a significant role in facilitating the digital transformation of PSEs.*

The differentiated impact of state ownership with varying characteristics on the digital transformation of PSEs. According to Wu (2011), state ownership in PSEs can take two main forms: financial investors and strategic investors. These forms have different effects on digital transformation.

As financial investors, state owners focus more on short-term profits. These investors aim to earn quick returns and may encourage PSEs to invest in projects that deliver fast results. After achieving the expected income, to reduce their own financial risks, these financial investors are more likely to choose an equity transfer to "cash out" (Wang et al. 2017, Batrancea, et al. 2013). However, digital transformation requires long-term investment in research and development (Gu et al. 2020, Sharma and Kohli, 2024, and Alzadjali et al. 2023). Financial investors are often unwilling to support projects that reduce profits in the short term. As a result, financial state ownership does not support the long-term strategy required for digital transformation. Based on these discussions, we propose the following hypothesis:

Hypothesis 2a: *As a financial investor, state ownership does not play a significant role in facilitating the digital transformation of PSEs.*

On the other hand, as strategic investors, state owners focus on broader goals like industrial upgrading and social development. They emphasize long-term strategies and actively participate in the strategic decision-making of PSEs. They provide resources and policy support to help enterprises improve their innovation and competitiveness (Ding and Suardi, 2019, Zhao et al. 2023,

and Wu et al. 2024). Strategic investors also supervise corporate decisions to ensure alignment with national goals. This oversight helps to restrain private shareholders who may ignore long-term development priorities.

State ownership as a strategic investor helps integrate resources for PSEs. This includes offering the technology, skilled workers, and financial resources needed for digital transformation (Ding et al. 2020; Liu et al. 2024). These resources strengthen the competitiveness of PSEs and improve their capacity for high-quality growth.

When potential investment projects conflict with national industrial development policies, state-owned shareholders use their information and reputation advantages to correct the actions of private shareholders. This increases the motivation of enterprises to implement digital transformation. Moreover, strategic investors often have abundant resources, which allow them to support technology, talent, and funding required for digital transformation. Therefore, strategic investors can significantly enhance the core competitiveness of PSEs and promote their high-quality development. And we introduce the following hypothesis:

Hypothesis 2b: *As a strategic investor, state ownership plays a significant role in facilitating the digital transformation of PSEs.*

Impact of state ownership on the digital transformation of PSEs in different business environments. According to institutional economics theory, the institutional framework of a region determines enterprise management strategies and decisions (Altin et al. 2017). A strong business environment, including developed market mechanisms, reliable legal systems, and adequate infrastructure, is essential for the growth of enterprises. The quality of the urban business environment directly impacts the development of local enterprises (Chan et al. 2016). In China, significant differences in resource allocation and geographic conditions across regions result in diverse business environments. These differences influence the relationship between state ownership and the digital transformation of PSEs.

In regions with weak business environments, the lack of market efficiency increases the role of the government in resource allocation (Tang et al. 2024). State ownership provides PSEs with reputational advantages, creating more development opportunities and increasing profitability. However, local governments in these regions often face financial and technical limitations. As a result, their ability to support digital transformation through state ownership is constrained.

In contrast, regions with strong business environments allow state ownership to have a more significant impact. PSEs in these areas benefit from better infrastructure, sound legal systems, and ample financial and technical resources. The collaboration between state ownership and the government enables effective resource integration. Moreover, intense market competition encourages PSEs to adopt digital transformation to maintain their competitive edge (Wang et al. 2021). The seamless legal framework reduces rent-seeking behavior, promoting efficient cooperation between enterprises and governments. Local governments also align their support with national strategies, further encouraging digital transformation.

In well-developed business environments, PSEs can leverage the advantages of state ownership to enhance their digital capabilities. This alignment helps enterprises achieve strategic goals and strengthens government support for their transformation. The state's role ensures long-term development and improves market competitiveness through digital innovation (Cheng and Cui, 2024). Therefore, we propose the following hypothesis:

Hypothesis 3: *In cities with a better business environment, state ownership assumes a more prominent role in facilitating the digital transformation of PSEs.*

Research design

Sample selection and data sources. Our study examines PSEs listed on the China stock exchanges as A-shares from 2012 to 2022. To ensure the reliability of the research, only original PSE listings are kept. Samples where SOEs changed their controlling rights after private capital conversion are excluded since such firms had close ties with relevant government agencies before restructuring. Other samples are eliminated according to the following: (1) Firms with unknown ultimate owners; (2) Firms with ST or *ST; (3) Firms with serious data deficiency; and (4) Firms in the financial industry. After the above screening, our sample includes a total of 4163 observations. The data on corporate finance and personal characteristics of board members come from the Wind database, and the data related to the digital transformation of enterprises come from the firms' annual reports. The analysis is conducted using Stata 17.

Definition and measurement of variables

Dependent variable. The dependent variable in our study is the digital transformation of enterprises (*DT*). At present, research on this concept is based mainly on qualitative analysis. There is scant literature on this from a quantitative perspective. State laws do not require listed companies to disclose information about their digital transformation; therefore, it is usually difficult to learn about their digital transformation from their public financial data. In recent years, some listed firms have taken the initiative to disclose information on their “digital transformation” in their annual reports, which can be regarded as an emphasis on digital transformation strategies and has strong representativeness. Hence, we gauged digital transformation by analyzing the frequency of terms associated with “digital transformation” within the company's annual report. First, based on the study by Wu et al. (2021) on the characteristic lexicon of “digital transformation,” the level of implementing digital transformation strategies for enterprises can be roughly summarized as “bottom technology application” and “technical practice application.” Specifically, the underlying technology — “ABCD” technology—is represented by artificial intelligence (A), blockchain (B), cloud computing (C), and data (D), and specifically includes 48 keywords. However, technical practice usually involves a variety of professional technologies; thus, it is no longer suitable to use the classification standard of the above four types of technical keywords. It is more reasonable to determine the keywords according to actual application scenarios. After sorting and summarizing, we obtained a total of 35 keywords. Figure 1 shows the specific keyword map. Then, we employed a Python crawler to compile the annual reports of PSEs listed as A-shares on the Shanghai and Shenzhen exchanges. The Java PDF box library was utilized to extract all textual content, enabling us to then assess the frequency of keywords associated with “digital transformation.” Thereafter, according to the sentences presented by the keyword “digital transformation,” the related words with negative expressions, such as “no,” before the keywords were eliminated, and the content of the non-company information (such as the brief introduction of customers and suppliers) related to the keyword “digital transformation” was eliminated. Finally, the keyword frequency of four technical directions was sorted and summarized to establish the index system for enterprise digital transformation. Because of the “right-bias” characteristics of this type of data, we also performed logarithmic processing in the empirical analysis.

In our subsequent analysis, to more accurately portray the mediating influence of the digital transformation of PSEs on innovation performance, we utilized the yearly count of invention patents along with the cumulative sum of design and utility model patents for the firm. These metrics collectively provide a comprehensive measure of their innovation performance. The data were acquired from the patent search and analysis website of the China National Intellectual Property Administration.

Explanatory variable. Our explanatory variable is State ownership (*State*). According to the research of Yu et al. (2022a), whether or not PSEs have state ownership (*State1*) and the shareholding ratio of state-owned shareholders (*State2*) can be used as measurements.

Moderating variables. In our extended analysis, we introduced the economic policy uncertainty (EPU) variable to explore whether state ownership continues to play a significant role in promoting the digital transformation of PSEs, even in the presence of uncertain economic policies. As for the measurement of economic policy uncertainty, we refer to the “China Economic Policy Uncertainty Index” constructed by Huang and Luk (2020), which comprehensively reflects the fluctuation of the country's macro-economic policy every month; the larger the value of the index, the higher the policy uncertainty of the country that year.

Instrumental variable. In the endogeneity test, we select the total market value of state-owned listed firms in the cities where the sample firms are located each year and take their natural logarithm value, which is the instrumental variable *SV* of the study.

Control variables. According to the research of Zhou et al. (2017), we select the firm size (*Size*), firm growth (*Growth*), listed years (*Time*), operating performance (*ROA*), debt ratio (*Lev*), cash holding (*Cash*), and the proportion of directors with a science and engineering background (*SCD*) as control variables. That is because that those control variables affect firm's innovation and digital transformation. Moreover, based on the high-risk characteristics of digital transformation, whether the firm will implement this major strategy also depends on the will of the actual controlling shareholder (Liu et al. 2022); thus, we controlled the shareholding ratio of the largest shareholder (*Top1*). In addition, in the regression analysis, we also controlled for the industry (*IND*) and year (*YR*) of the firm.

In the following part, we try to discuss how the above variables contribute to understanding the digital transformation process in PSEs. *Size*: Larger companies typically have more financial and human resources to invest in new technologies and digital systems. They are better equipped to manage and scale digital transformation projects. Larger firms can also reduce the cost of adopting new technologies through economies of scale, making digital transformation more sustainable. Meanwhile, company size is related to the availability of resources. These resources are crucial for innovation and technology adoption. Larger companies usually have more available resources, which allows them to bear the cost and risks of digital transformation.

Growth: Companies with growth often need more digital systems to manage larger operations, more complex processes, and broader customer bases. Growth leads to the adoption of new technologies to maintain or accelerate expansion and improve efficiency. Furthermore, companies under growth pressure look for new capabilities to maintain their performance. Digital transformation is part of this capability restructuring, helping companies expand and improve through technology.

Time: Companies that have been listed for longer tend to be more mature and better able to accept digital transformation.

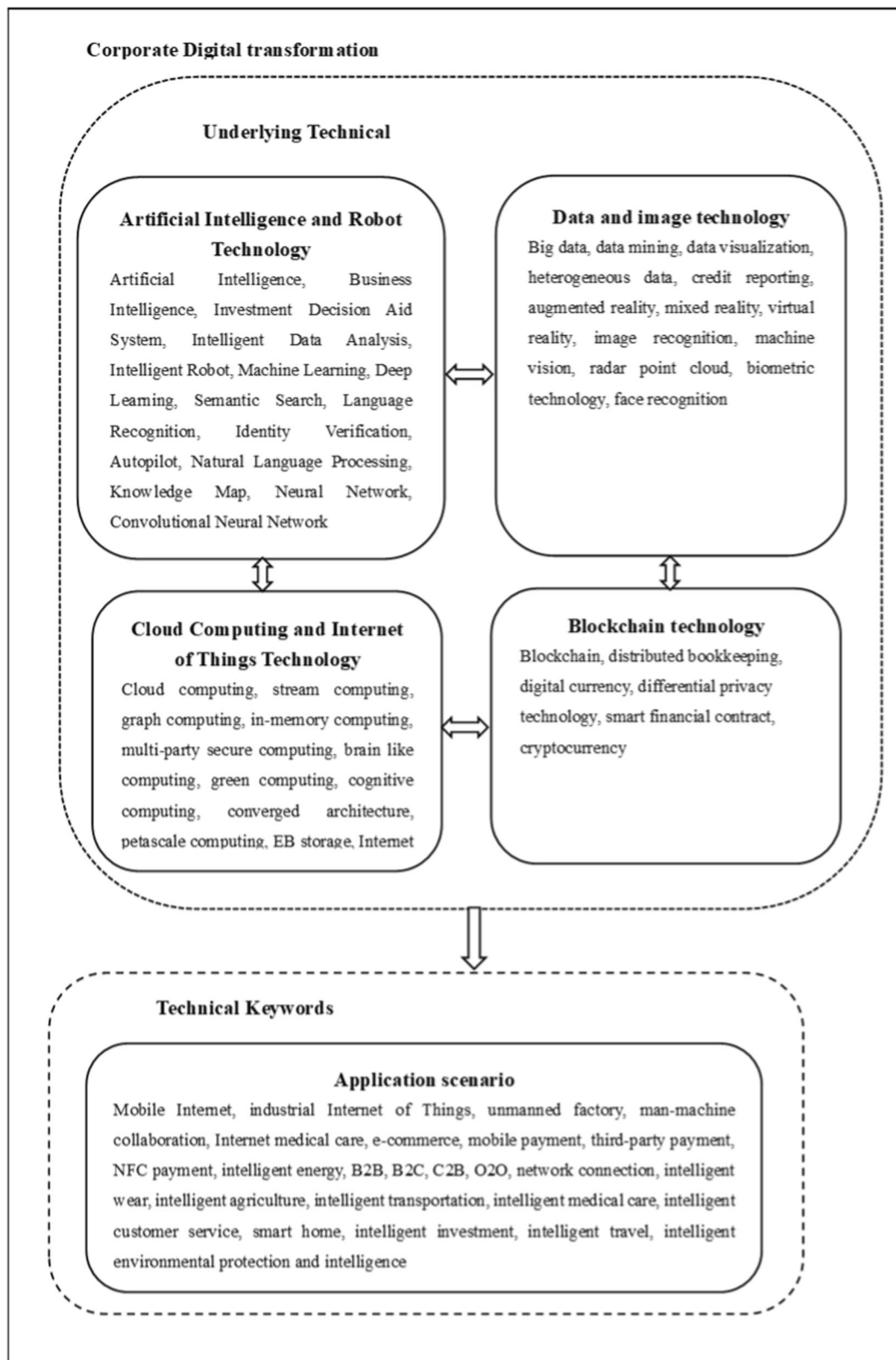


Fig. 1 Keywords involved in the digital transformation of firms. Source: Based on the Research of Wu et al. (2021).

These companies usually have stronger management structures, access to capital, and proven financial performance (Cocis et al. 2021), all of which are critical for large-scale technology projects. Moreover, companies listed for a longer time face stronger external pressures, such as from investors, customers, and

regulators, to modernize. This may push them to adopt digital technologies.

ROA: Companies with better operating performance are more likely to be financially healthy and able to invest in digital transformation. Strong performance indicates a company's

Table 1 Variable definition.

Definition	
Dependent Variable	
<i>DT</i>	Measure according to the previous method
<i>Patent</i>	The sum of the number of invention patents and the total number of design patents and utility model patents of the firm in each year+1, and its natural logarithm value
Explanatory variables	
<i>State1</i>	Among the top 10 shareholders, the value is 1 if there are state-owned shareholders, otherwise, it is 0
<i>State2</i>	Cumulative number of shares held by state-owned shareholders among the top 10 shareholders/total number of shares held by the top ten shareholders
Moderating Variable	
<i>EPU</i>	The economic policy uncertainty index data of each month in the study year are summed up and divided by 12 to obtain the economic policy uncertainty index of each year in the study year
Instrumental Variable	
<i>SV</i>	The total market value (Unit: 100 million RMB) of state-owned listed firms in the cities where the sample firms are located within each year is selected and their natural logarithm value taken
Control Variables	
<i>Size</i>	Natural logarithmic value of total assets
<i>Time</i>	The specific number of years of listing
<i>ROA</i>	Net profit/total assets
<i>Lev</i>	Total liabilities/total assets
<i>Cash</i>	Net cash flow/total assets
<i>SCD</i>	Number of directors with a technical background in science and engineering/total number of board members
<i>Top1</i>	Number of shares held by the largest shareholder/total number of shares held by the top 10 shareholders

willingness and ability to take on new initiatives, including technology adoption (Mosciov et al. 2010, and Batrancea, 2021, and Batrancea et al. 2022). Well-performing companies can reconfigure their resources to innovate. Digital transformation is a part of this resource restructuring, allowing companies to improve or maintain performance in a digital world.

Lev: A higher debt ratio may mean that a company faces financial strain or constraints, which could limit its ability to invest in digital transformation. Lower debt ratios give companies more flexibility to invest in innovations like digital technologies. Highly indebted companies often prioritize internal financing, which may limit their ability to make investments in large-scale projects like digital transformation. This may lead to delays or lack of commitment to digital initiatives.

Cash: Companies with more cash holdings typically have the financial advantage to fund digital transformation themselves, without relying on external financing. Sufficient cash flow is crucial for absorbing the upfront costs and experimenting with digital technologies. Furthermore, companies with abundant cash flow may invest in strategic projects like digital transformation to increase long-term value. Cash holdings offer a buffer that allows companies to experiment with new technologies without worrying about financial instability.

SCD: A higher proportion of directors with science and engineering backgrounds often leads to a more positive attitude toward embracing technological change and digital transformation. These directors are more likely to understand the benefits and challenges of adopting digital technologies. The characteristics of top management, including their education and background, influence company decisions. Directors with strong technical backgrounds are more likely to support technology adoption, including digital transformation.

Top1: The shareholding ratio of the largest shareholder affects governance and decision-making. A concentrated ownership structure often leads to more decisive leadership, which may accelerate digital transformation. If the largest shareholder is risk-averse or conservative, it may delay investment in digital technologies. Moreover, companies with dominant shareholders

can reduce agency costs by aligning ownership and control. The largest shareholder may drive digital transformation if it aligns with long-term company goals.

The main variables used in the study and their definitions are listed in Table 1.

Research model. The research hypotheses proposed in our study are examined by constructing the following model:

$$DT_{ij,t+1} = \alpha_0 + \alpha_1 State_{ij,t} + \sum \alpha_i CV_{ij,t} + \gamma_t + \eta_j + \varepsilon_{ij,t} \quad (1)$$

Here, *DT* is the digital transformation of firms, *State* is the state ownership variables *State1* and *State2*, *CV* represents a series of control variables, γ_t and η_j represent the annual (YR) and industry (IND) fixed effects controlled in this study, respectively, and $\varepsilon_{ij,t}$ is a random error term. It is noteworthy that due to the potential time lag in the influence of state ownership on the digital transformation of PSEs, the dependent variable should be adjusted to $DT_{ij,t+1}$. In the above model, particular emphasis is placed on the coefficient α_1 associated with the state ownership variable. This coefficient quantifies the impact of state ownership on the digital transformation of firms.

Empirical analysis

Descriptive statistics of research variables. Table 2 reports the descriptive statistical results of the research variables.

Table 2 shows that the mean value and standard deviation of *DT* are 1.374 and 2.358, respectively, which indicates that the digital transformation degree of the sample firms is generally not high, and there are still big differences in the transformation capabilities of different firms. The mean value of *State1* is 0.526, indicating that more than half of the sample firms have state-owned shareholders. The mean value of *State2* is 0.159, which shows that with the continuous advancement of “mixed reform,” state-owned shareholders have become an important force that cannot be ignored among PSEs. The mean values of *ROA* and *Lev* are 0.067 and 0.485, respectively, indicating that the profitability of the sample firms is generally good, and liabilities are also controlled in a

reasonable range. The mean value of *SCD* is 0.193, accounting for nearly 20%, which shows that in recent years, under the background that the state has vigorously promoted the innovation and development of enterprises, more talent with a technical background in science and engineering has served as directors in PSEs. The mean value of *TOP1* is 0.284, which indicates that the largest shareholder of the firm has a strong influence.

Regression results

The impact of state ownership on the digital transformation of PSEs. Table 3 reports the regression results for Hypothesis 1.

Columns (1) and (3) in Table 3 only test the variables *State1* and *State2* by regression. The results show that the coefficients of *State1* and *State2* are significantly positive at least at the level of 5%. After adding a series of control variables in columns (2) and (4), the coefficients of *State1* and *State2* are significantly positive at least at the level of 10%, indicating that PSEs with state ownership can effectively help their digital transformation, verifying Hypothesis 1. Among the control variables, the coefficient of *SCD* is significantly positive at least at the level of 10%, which indicates that the higher the proportion of directors with a technical background in science and engineering, the more favorable it is for the implementation of the digital transformation strategy. The coefficients of the other controlled variables do not show statistical significance in the regression.

Table 2 Descriptive statistics of main research variables.

Variables	Obs	Mean	Min	Median	Max	SD.
<i>DT</i>	4163	1.374	0.000	0.863	5.216	2.358
<i>State1</i>	4163	0.526	0.000	1.000	1.000	0.325
<i>State2</i>	4163	0.159	0.000	0.062	0.327	0.163
<i>Size</i>	4163	23.412	8.376	19.237	45.207	12.495
<i>Time</i>	4163	14.628	1.000	16.000	25.000	9.271
<i>ROA</i>	4163	0.067	-0.218	0.029	0.384	0.154
<i>Lev</i>	4163	0.485	0.031	0.427	0.793	0.289
<i>Cash</i>	4163	0.074	-0.476	0.281	0.625	0.394
<i>SCD</i>	4163	0.193	0.000	0.167	0.714	0.428
<i>Top1</i>	4163	0.284	0.145	0.312	0.629	0.512
<i>Patent</i>	4163	2.518	0.000	2.692	5.342	1.783
<i>EPU</i>	4163	235.712	113.549	195.267	371.753	93.571
<i>SV</i>	4163	5.238	1.547	4.391	8.732	2.358

The impact of state ownership with different characteristics on the digital transformation of PSEs. At present, the state ownership holders in PSEs can be divided roughly into the following two types: (1) The State-owned Assets Supervision and Administration Commission (SASAC) or other organizations under the jurisdiction of governments at all levels; and (2) SOEs. Specifically, category (1) state ownership holders usually have a strong official color. The behavior of such state-owned shareholders reflects their specific will to follow government policy. Under the assumption that the state actively wants to help the digital transformation of PSEs, such state ownership in PSEs can be considered an important way for the state to support its digital transformation strategy; as such, they are regarded as strategic investors. In category (2), state ownership holders are mainly SOEs that are looking for financial performance; their official color has faded. Such state ownership in PSEs is based more on economic considerations; thus, they are regarded as financial investors. If a PSE has both of these types of state owners, given the background that the state has encouraged PSEs to pursue high-quality development in recent years, SOEs need to actively respond to the call of the state and actively cooperate with the government's development policy; thus, this kind of mixed state ownership is also regarded as functioning as a strategic investor. Table 4 reports the regression results for Hypothesis 2.

Columns (1) and (2) in Table 4 show that among the strategic investors, the coefficients of *State2* are all significantly positive at the level of 1%. Columns (3) and (4) show that among the financial investors, the coefficient of *State2* does not pass the statistical significance test. The results indicate that as a strategic investor, state ownership plays a significant role in helping the digital transformation of PSEs. Correspondingly, state ownership as a financial investor does not help their digital transformation. This verifies Hypothesis 2. State ownership in PSEs that functions as a strategic investor is based on China's current development policy. By giving play to their roles in resource provision and governance, governments at all levels offer effective support to PSEs in implementing digital transformation. However, SOE state owners in PSEs as financial investors, based on their own economic needs, pay more attention to the short-term financial performance of these PSEs. Thus, they pay scant attention to major strategies involving the long-term development of enterprises, such as digital transformation.

Table 3 Impact of state ownership on the digital transformation of PSEs.

Variables	DT			
	(1)	(2)	(3)	(4)
<i>State1</i>	0.392*** (0.008)	0.138** (0.026)		
<i>State2</i>			0.245** (0.041)	0.108* (0.063)
<i>Size</i>		0.047 (0.163)		0.194 (0.273)
<i>Time</i>		0.235 (0.192)		0.056 (0.247)
<i>ROA</i>		0.114* (0.086)		0.079 (0.135)
<i>Lev</i>		0.368 (0.249)		0.342 (0.182)
<i>Cash</i>		0.152 (0.171)		0.231* (0.094)
<i>SCD</i>		0.139** (0.036)		0.227* (0.059)
<i>Top1</i>		0.453 (0.158)		0.204* (0.361)
<i>Const</i>	0.281 (0.245)	0.079* (0.062)	0.173 (0.348)	0.276 (0.423)
<i>IND & YR</i>	Yes	Yes	Yes	Yes
Adj. R ²	0.162	0.215	0.164	0.223
F Value	17.853***	20.617***	26.584***	23.629***
Obs.	4163	4163	4163	4163

Note: The numbers in parentheses are *P* values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

Table 4 Impact of state ownership with different characteristics on the digital transformation of PSEs.

Variables	DT			
	Strategic investor		Financial investor	
	(1)	(2)	(3)	(4)
State2	0.367*** (0.000)	0.254*** (0.000)	0.069 (0.135)	0.213 (0.169)
Size		0.193 (0.217)		0.247 (0.216)
Time		0.145 (0.368)		0.088 (0.314)
ROA		0.179 (0.154)		0.264 (0.278)
Lev		0.041 (0.375)		0.319 (0.188)
Cash		0.315 (0.198)		0.283 (0.147)
SCD		0.162* (0.094)		0.054* (0.069)
Top1		0.058* (0.067)		0.184 (0.126)
Const	0.013* (0.076)	0.368 (0.273)	0.145 (0.389)	0.336 (0.194)
IND & YR	Yes	Yes	Yes	Yes
Adj. R ²	0.168	0.231	0.165	0.227
F Value	21.365***	19.018***	16.724***	25.516***
Obs.	1838	1838	351	351

Note: The numbers in parentheses are *P* values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

Table 5 Impact of state ownership on the digital transformation of PSEs in different business environments.

Variables	DT			
	Poor business environment	Good business environment	Poor business environment	Good business environment
	(1)	(2)	(3)	(4)
State1	0.094 (0.256)	0.371*** (0.004)		
State2			0.053 (0.146)	0.269*** (0.008)
Size	0.338 (0.197)	0.026 (0.157)	0.169 (0.234)	0.275* (0.061)
Time	0.194 (0.312)	0.382 (0.245)	0.053 (0.295)	0.341 (0.127)
ROA	0.346 (0.151)	0.073* (0.087)	0.194 (0.236)	0.015 (0.308)
Lev	0.048 (0.364)	0.129 (0.258)	0.313 (0.276)	0.062 (0.183)
Cash	0.162* (0.058)	0.314 (0.259)	0.123 (0.157)	0.039 (0.324)
SCD	0.125** (0.036)	0.021* (0.084)	0.419* (0.056)	0.148** (0.029)
Top1	0.091 (0.174)	0.276 (0.134)	0.112* (0.095)	0.209 (0.223)
Const	0.376 (0.159)	0.108* (0.077)	0.239* (0.083)	0.075 (0.248)
IND & YR	Yes	Yes	Yes	Yes
Adj. R ²	0.248	0.251	0.237	0.243
F Value	20.639***	26.285***	17.927***	22.318***
Obs.	878	2934	878	2934

Note: The numbers in parentheses are *P* values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

The impact of state ownership on the digital transformation of PSEs in different business environments. For the assessment of the local business environment in which the firm is situated, we referred to the 2018 “Urban Business Environment Index” constructed by Li (2019) as an important basis for our grouping. Specifically, the samples with an index score higher than or equal to the average value in the city where the firm is located are regarded as cities with good business environments, while those with an index score lower than the average are regarded as cities with poor business environments. In addition, the regression results for Hypothesis 2 confirm that state ownership that functions as a financial investor does not play a significant role in helping the digital transformation of the PSEs. To better analyze the impact of state ownership on the digital transformation of PSEs, in Table 5 and the following empirical examination, we delete the sample where state ownership functions as a financial investor. Table 5 reports the regression results for Hypothesis 3.

We can see in columns (1) and (3) in Table 5 that although the coefficients of *State1* and *State2* are shown as positive in the regression, they are not statistically significant. Columns (2) and

(4) show that the coefficients of *State1* and *State2* are both significantly positive at the level of 1%. This indicates that state ownership plays a more obvious role in helping the digital transformation of PSEs in cities with better business environments, thus verifying Hypothesis 3. In fact, in cities with poor business environments, local governments generally lack sufficient technical and human resources, and the financial state of these local governments is relatively constricted. Under such circumstances, it is difficult to provide substantial support for PSEs to implement digital transformation strategies through state ownership participation. In cities with good business environments, research institutes and universities are often concentrated there. This can provide the necessary manpower and technical support for enterprises to implement a digital transformation, with local governments often having rich financial resources. Amid the backdrop of the nation’s robust digital economy advancement, state ownership participation can be an effective means to bolster the digital transformation of private enterprises, consequently fostering the high-quality development of local industries.

Table 6 Impact of state ownership on the digital transformation of PSEs under economic policy uncertainty.

Variables	DT				
	(1)	(2)	(3)	(4)	(5)
State1		0.163*** (0.004)	0.094*** (0.008)		
State2				0.145*** (0.001)	0.068*** (0.007)
EPU	-0.461*** (0.000)	-0.358*** (0.009)	-0.219* (0.058)	-0.402** (0.036)	-0.283* (0.094)
EPU×State1			0.186** (0.029)		
EPU×State2					0.227** (0.035)
Size	0.294 (0.351)	0.174 (0.123)	0.065 (0.192)	0.175* (0.068)	0.134 (0.259)
Time	0.138 (0.207)	0.051 (0.249)	0.208 (0.167)	0.097 (0.162)	0.192 (0.316)
ROA	0.219 (0.148)	0.263* (0.087)	0.151 (0.263)	0.184 (0.152)	0.357* (0.095)
Lev	0.342 (0.341)	0.143 (0.258)	0.368 (0.154)	0.265 (0.139)	0.144 (0.263)
Cash	0.251 (0.295)	0.116 (0.328)	0.229* (0.072)	0.192 (0.248)	0.012 (0.185)
SCD	0.023* (0.076)	0.347** (0.024)	0.052** (0.036)	0.365* (0.092)	0.166* (0.081)
Top1	0.187* (0.092)	0.017 (0.149)	0.249 (0.358)	0.228 (0.265)	0.293 (0.179)
Const	0.046 (0.158)	0.253* (0.082)	0.418* (0.075)	0.056 (0.347)	0.132* (0.065)
IND & YR	Yes	Yes	Yes	Yes	Yes
Adj. R ²	0.219	0.226	0.241	0.228	0.245
F Value	20.263***	18.544***	24.609***	23.153***	21.523***
Obs.	3812	3812	3812	3812	3812

Note: The numbers in parentheses are *P* values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

Further analysis

The impact of state ownership on the digital transformation of PSEs under uncertain economic policies. Economic uncertainty pertains to the challenges faced by economic entities in accurately forecasting the timing, nature, and manner of potential adjustments in the current economic policies of the government (Gu et al. 2021). Due to the relatively less robust standing of PSEs than of SOEs in China, PSEs tend to be more responsive to changes in economic policies. Economic policy uncertainty often exerts a more pronounced influence on their strategic decision-making processes. When PSEs are faced with a high policy uncertainty, evaluating policy directions becomes more difficult, thereby raising investment risk and making their development prospects murky (Ma and Hao, 2022). When faced with a lack of investment confidence, enterprises often opt for conservative management strategies, which may involve postponing initial investment plans or scaling back investment endeavors (Cui et al. 2021). For PSEs undergoing digital transformation, the reduction or even interruption of financial subsidies and financing preferences caused by economic policy uncertainty will increase their business risks, thus adversely affecting the implementation of their digital transformation strategy. In that case, the private controlling shareholders, whose business goal is to maximize profits, will be reluctant to invest too much in a digital transformation strategy—namely, a large investment with high risk—based on possible business risks in the future. To investigate whether state ownership remains a substantial factor in aiding the digital transformation of PSEs amid economic policy uncertainty, we introduced the EPU variable. Table 6 reports the corresponding regression results.

We can see in column (1) in Table 6 that the coefficient of *EPU* is significantly negative at the 1% level, indicating that economic policy uncertainty is not conducive to the implementation of the digital transformation strategy of PSEs. After adding the variables of state ownership into the model, columns (2) and (4) show that the coefficient of *EPU* is significantly negative at least at the 5% level, and the coefficients of *State1* and *State2* are significantly positive at the 1% level. To explore whether economic policy uncertainty will affect the digital transformation of PSEs with state ownership, we added interaction terms *EPU*×*State1* and *EPU*×*State2* in columns (3) and (5), respectively. The results show that the coefficients of *State1* and *State2* are still significantly positive at the 1% level, while those of *EPU* are

significantly negative at the 10% level, and the coefficients of *EPU*×*State1* and *EPU*×*State2* are significantly positive at least at the 5% level, indicating that the risks caused by economic policy uncertainty are not conducive to the implementation of PSE digital transformation. However, state ownership can avoid the adverse impact of policy risks on the digital transformation of PSEs to a certain extent, and the degree of risk avoidance can reach 84.9% (0.186/0.219) and 80.2% (0.227/0.283), respectively.

State ownership in PSEs can provide solid support for enterprises in implementing their digital transformation strategies. On the one hand, by virtue of information superiority, state ownership can eliminate the long-standing information asymmetry problem of PSEs, help enterprises access relevant information on macro-policy adjustments in time, enhance the accuracy of future risk assessment, and reduce the impact of policy uncertainty on business operations, thus ensuring the smooth implementation of digital transformation. On the other hand, the resource advantages brought by state ownership in PSEs are also particularly important to stabilize their digital transformation strategy and related investments. Under the impact of economic policy uncertainty, to avoid business risks, enterprises will take the initiative to cut or even give up some investments. As a high-risk characteristic, an investment related to digital transformation will easily become the first choice for enterprises to cut. As an important national strategy, the government departments behind the state-owned shareholders will make every effort to continuously provide enterprises with various resources, such as funds and equipment, for digital transformation to prevent PSEs from reducing their related investment and strengthen their digital construction.

The impact of state ownership on the digital transformation of PSEs with different industry characteristics. Digital transformation is not a simple technological change, but also the overall transformation of enterprise production and management mode and values. The implementation of this strategy usually has the characteristics of long-term uncertainty (Vial, 2019), thus profoundly affecting the strategic choice of digital transformation among PSEs with different industry characteristics. From the perspective of the enterprise's internal environment, enterprises engaged in traditional industries compared with those in emerging industries have a better foundation for implementing digital transformation. By establishing a

Table 7 Impact of state ownership on the digital transformation of PSEs with different industry characteristics.				
Variables	DT			
	Traditional industry (1)	Emerging industries (2)	Traditional industry (3)	Emerging industries (4)
State1	0.341 (0.259)	0.256*** (0.003)		
State2			0.305 (0.186)	0.273*** (0.002)
Size	0.161 (0.215)	0.021 (0.354)	0.284* (0.093)	0.351 (0.172)
Time	0.312 (0.176)	0.209 (0.183)	0.153 (0.202)	0.063 (0.259)
ROA	0.164* (0.085)	0.157 (0.243)	0.213 (0.169)	0.158 (0.124)
Lev	0.097 (0.218)	0.136 (0.104)	0.341 (0.237)	0.182 (0.347)
Cash	0.296 (0.124)	0.418* (0.059)	0.162 (0.238)	0.273 (0.261)
SCD	0.353* (0.089)	0.073* (0.064)	0.274** (0.031)	0.208* (0.057)
Top1	0.256 (0.283)	0.029 (0.196)	0.423* (0.057)	0.246* (0.091)
Const	0.337 (0.124)	0.243* (0.081)	0.139* (0.066)	0.178 (0.253)
IND & YR	Yes	Yes	Yes	Yes
Adj. R ²	0.227	0.236	0.224	0.241
F Value	25.816***	21.592***	27.065***	24.736***
Obs.	726	3086	726	3086

Note: The numbers in parentheses are P values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

big data processing center and integrating digital resources with technical data, the transmission efficiency of information within enterprises can be effectively improved, and the operation of enterprises can be monitored in real-time, which can significantly reduce operating costs, thus ensuring sound development of the enterprise (Jiang et al. 2022).

Viewed from an external enterprise environment standpoint, the primary objective of a digital transformation strategy for emerging businesses is to judiciously leverage digital technology to elevate their market competitiveness and refine their industrial framework (Zhang et al. 2023). The application of artificial intelligence, big data, and other information technologies by emerging enterprises can effectively reduce information costs and achieve coordinated development through the exchange of information across enterprises (Li et al. 2018). Additionally, emerging enterprises are actively committed to digital construction, which can obtain the latest market information, effectively alleviate long-standing information asymmetry between enterprises and the market, and quickly adjust their own development strategies to enhance their market competitiveness.

According to Huang et al. (2016) industry standard groupings that enterprises belong to, the industries of the sample firms are divided into emerging industries and traditional industries, to examine the impact of state ownership on the digital transformation of PSEs with different industry characteristics. Table 7 reports the corresponding regression results.

Columns (1) and (3) in Table 7 show that although the coefficients of *State1* and *State2* are positive, they are not statistically significant. The results of columns (2) and (4) show that the coefficients of *State1* and *State2* are all significantly positive at the 1% level, which indicates that state ownership in PSEs in emerging industries helps their digital transformation. Compared with PSEs engaged in traditional industries, digital transformation is more important for enterprises in emerging industries, and state ownership in such enterprises also plays a more significant role in helping their digital transformation. On the one hand, new and high-tech-driven enterprises need digital technology to establish their competitive advantage in the industry and gain more from digital transformation. By implementing a digital transformation strategy, emerging enterprises will have a stronger incentive to improve their capacity building, thus enhancing the supporting effect of state ownership in such enterprises. On the other hand, China is undergoing a phase of economic transformation and

progress, and it urgently needs more emerging technology enterprises that can create high-added value. Diverse policies are also favoring these enterprises to drive the high-quality development of the national economy. According to the policy of “mixed reform” issued by the state recently, we can see that state ownership should invest in non-public enterprises with great development potential and support extensive, new technology. Under the guidance of relevant policies, state ownership in PSEs engaged in emerging industries will better show the “supporting hand” of the government, thus “escorting” the implementation of a digital transformation strategy for such enterprises.

The impact of state ownership on the innovation performances of PSEs. The previous regression results confirm that state ownership in PSEs has a significant positive impact on their digital transformation. Nevertheless, can state ownership enhance the innovation performance of PSEs while simultaneously facilitating their digital transformation? To illustrate the positive consequences of state ownership in enabling the digital transformation of enterprises, we referred to the research methods of Hao et al. (2020) and built the following simultaneous equation model for regression analysis:

$$Patent_{i,j,t+1} = \beta_0 + \beta_1 DT_{i,j,t} + \beta_2 Size_{i,j,t} + \beta_3 Time_{i,j,t} + \gamma_t + \eta_j + \mu_{i,j,t} \tag{2}$$
$$DT_{i,j,t} = \varphi_0 + \varphi_1 Patent_{i,j,t+1} + \varphi_2 ROA_{i,j,t} + \varphi_3 LEV_{i,j,t} + \varphi_4 Cash_{i,j,t} + \varphi_5 SCD_{i,j,t} + \varphi_6 TOP1_{i,j,t} + \gamma_t + \eta_j + \nu_{i,j,t} \tag{3}$$

In the above model, we first divide PSEs into “Group with state ownership” and “Group without state ownership” according to the principle of whether they have state ownership and then use the three-stage least square (3SLS) estimation for regression analysis. If the coefficient of the variable *DT* is significantly positive in the regression, it means that with the continuous advancement of the digital transformation of the PSEs, their innovation performance effectively improves. Moreover, to reflect the mediating effect of digital transformation of PSEs between state ownership and innovation performance, the innovation performance of PSEs is measured by the number of invention patents and the sum of design patents and utility model patents in each year. In addition, referring to the research of Li et al. (2020),

Table 8 State ownership, digital transformation, and innovation performances of PSEs.

Variables	Group of PSEs with state ownership		Group of PSEs without state ownership		Difference test
	Patent (1)	DT (2)	Patent (3)	DT (4)	Chow Test (5)
DT	0.451*** (0.000)		0.036*** (0.008)		0.058*** (0.004)
Size	0.084 (0.236)		0.263* (0.072)		
Time	0.293 (0.316)		0.174 (0.257)		
Patent		0.374*** (0.002)		0.069*** (0.007)	
ROA		0.138* (0.096)		0.282 (0.158)	
Lev		0.215 (0.162)		0.307 (0.284)	
Cash		0.357 (0.149)		0.061* (0.078)	
SCD		0.187* (0.061)		0.234** (0.018)	
Top1		0.362* (0.095)		0.218* (0.076)	
Const	0.248 (0.159)	0.151* (0.078)	0.236* (0.097)	0.083 (0.246)	
IND & YR	Yes	Yes	Yes	Yes	
Adj. R ²	0.204	0.236	0.208	0.241	
F Value	23.156***	25.208***	22.437***	26.895***	
Obs.	1838	1838	1974	1974	

Note: The numbers in parentheses are *P* values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

we also use the variable innovation performance by one lag period ($Patent_{i,j,t+1}$) for the regression. Table 8 reports the corresponding regression results.

Columns (1) and (3) in Table 8 show that the coefficients of variable *DT* are all significantly positive at the 1% level, indicating that the continuous advancement of the digital transformation of PSEs can improve their innovation performance. In the group of PSEs with state ownership, the coefficient of *DT* is 0.451, which is significantly higher than that of *DT* in the group of PSEs without state ownership of 0.036; the difference test shows that it is highly significant, indicating that PSEs with state ownership has effectively improved their innovation output because of their faster digital transformation. In addition, columns (2) and (4) show that the coefficient of the variable *Patent* is significantly positive at the 1% level, which indicates that although there is some endogeneity between digital transformation and innovation performance, the 3SLS estimation in this study can largely avoid this problem. In sum, state ownership can accelerate the digital transformation of PSEs, thus improving their innovation performance.

Endogenous test. The analysis shows that state ownership in PSEs significantly supports their digital transformation. However, it is necessary to consider potential endogeneity issues. Some PSEs may implement digital transformation strategies more effectively, which could attract government support through state ownership. This could result in reverse causality in the regression results. To address this concern and account for omitted variable bias, we use the instrumental variable (IV) method, as suggested by Yao et al. (2018).

In this study, we use the total market value of SOEs in the cities where the sample firms are located and its natural logarithm as the instrumental variable (SV). This variable reflects the achievements of market-oriented reforms and is positively related to state ownership. At the same time, it does not directly influence the digital transformation of PSEs, making it an appropriate instrumental variable.

We apply the two-stage least squares (2SLS) method to handle potential endogeneity (Batranea, 2022, Batrancea et al. 2023). We assume that the SV is an instrumental variable with a positive correlation with state-owned equity because the total market value of a city's SOEs can better reflect the achievements made by the local SOEs through market-oriented reform. If the city's SOEs have a larger total market value, they have a stronger influence in the local area and can directly participate in local PSEs. Moreover,

Table 9 Instrumental variable first-stage weak instruments and endogenous test.

Cragg-Donald value	Stock-Yogo bias critical value	Durbin-Wu-Hausman chi-sq test	P-value
18.795	9.834 (15%)	5.463	0.029

there is no direct relationship between this variable and the digital transformation of PSEs; thus, it is completely suitable as an instrumental variable in this study. Table 9 reports the results of the weak instrumental variable and endogenous test in the first stage of the instrumental variable.

Table 9 shows the results of the weak instrumental variable and endogenous tests in the first stage. The Cragg-Donald value is 18.795, which is greater than the Stock-Yogo bias critical value of 9.834 (15%). This means the hypothesis of a weak instrumental variable is rejected. The Durbin-Wu-Hausman test gives a chi-square value of 5.463 ($p = 0.029$), showing that state ownership variables are endogenous. This confirms the need for instrumental variables in the analysis.

Table 10 presents the 2SLS regression results using instrumental variable. Columns (1) and (2) show the first stage of the analysis, where the coefficients of SV are significantly positive at the 1% level. Columns (3) and (4) show the second stage, where the coefficients of *State1* and *State2* are also significantly positive at the 1% level. These results are consistent with the earlier findings. This confirms that the previous empirical results are robust and unaffected by endogeneity.

Conclusion

Finding. This study investigates the role of state ownership in supporting the digital transformation of PSEs. The findings confirm that state ownership significantly contributes to the digital transformation of PSEs. However, its effectiveness varies depending on the type of ownership. State ownership that acts as a strategic investor exerts a stronger influence on the implementation of digital transformation strategies compared to state ownership serving as a financial investor, which plays a limited role.

The study further reveals that the impact of state ownership is more pronounced in cities with favorable business environments. In such settings, state-owned shareholders provide critical

Table 10 Endogenous test: 2SLS instrumental variable estimation.				
Variables	State1	State2	DT	
	(1)	(2)	(3)	(4)
SV	0.269*** (0.005)	0.372*** (0.000)		
State1			0.184*** (0.000)	
State2				0.439*** (0.000)
Size			0.216 (0.158)	0.051 (0.316)
Time			0.128 (0.345)	0.0713 (0.284)
ROA			0.319 (0.163)	0.105* (0.067)
Lev			0.263 (0.273)	0.066 (0.138)
Cash			0.245* (0.051)	0.183 (0.278)
SCD			0.069* (0.072)	0.132** (0.049)
Top1			0.147* (0.069)	0.318 (0.127)
Const	0.419* (0.063)	0.112 (0.273)	0.168* (0.095)	0.235* (0.084)
IND & YR	Yes	Yes	Yes	Yes
Adj. R ²	0.176	0.173	0.229	0.235
F Value	28.418***	26.075***	29.437***	17.328***
Obs.	3812	3812	3812	3812

Note: The numbers in parentheses are *P* values. *, **, *** are statistically significant in $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

resources, align enterprise strategies with national policies, and mitigate the negative effects of policy risks. This highlights the role of state ownership as a stabilizing factor during periods of economic uncertainty. Moreover, state ownership is particularly effective in facilitating digital transformation for PSEs operating in emerging industries. These enterprises benefit from improved innovation output as their pace of digital transformation accelerates under state ownership.

Implications. This study offers several implications for practice and policy. Firstly, governments play a crucial role in addressing the resource constraints faced by PSEs, such as insufficient funding, technology, and talent, which hinder their digital transformation. By leveraging state ownership, governments can provide necessary resources and establish governance systems that align enterprise strategies with national industrial development goals. This approach not only supports the digital transformation of PSEs but also promotes the sustainable growth of the digital economy.

Secondly, the type of state ownership is critical for the success of digital transformation. Mixed ownership structures may confine state-owned shareholders to a financial investor role, limiting their strategic influence. To overcome this, state-owned shareholders must actively participate in the decision-making processes of PSEs. This deeper integration can unlock their governance advantages, which are essential for fostering long-term development and enhancing digital transformation capabilities.

Thirdly, the quality of the business environment is a key external factor influencing the success of digital transformation. Local governments should focus on improving infrastructure, optimizing legal systems, and creating favorable market conditions. These efforts will provide the necessary foundation for enterprises to achieve digital transformation and accelerate the growth of the digital economy.

Furthermore, policy consistency is vital for supporting enterprise digital transformation, especially during periods of economic uncertainty. Governments should ensure the stable implementation of long-term industrial policies aligned with national development goals. Additionally, targeted support should be provided to traditional industries that face greater challenges in the digital transformation process. Tailored policies can enhance their capacity to upgrade and innovate, ensuring these industries remain competitive.

Finally, the effective use of big data technology is essential for improving enterprise productivity and innovation during digital transformation (Salamzadeh et al. 2025). Governments should enhance regulations and oversight related to data management, promote the integration of data resources into the market, and encourage enterprises to fully utilize data elements. By fostering the comprehensive development of data resources, governments can establish big data technology as a driving force behind high-quality economic growth.

Limitations and future research. The data is based on Chinese PSEs, so the findings may not exactly apply to other countries. Cultural and institutional differences could change the relationship between state ownership and digital transformation. The study also uses panel data from 2012 to 2022, which does not allow for an analysis of long-term effects.

Future research could address these issues. Cross-country studies could explore how cultural and institutional factors affect digital transformation. Long-term data could be used to study the lasting impact of state ownership. Researchers could also examine how shareholder structures influence digital transformation strategies in different industries. These efforts could provide a deeper understanding and broader insights for policymakers and businesses.

Data availability

The data used in this study came from CSMAR database (China Stock Market & Accounting Research Database) (<https://data.csmar.com/>). We have not been authorized to disclose the database. The datasets generated during the current study are available from the corresponding author upon reasonable request.

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Note

1 Data from China Government Report.

References

Altin M, Memili E, Sönmez S (2017) Institutional economics and firm creation in the hospitality and tourism industry: A comparative analysis of developing and developed economies. *Tour Econ* 23(7):1381–1397

- Alzadjali AH, Adedeji MJ, Adwan OMJ (2023) Adopting a learning organization perspective for improving human resources service quality during digital transformation. *J Chin Hum Resour Manag* 14(3):18–35
- Batrancea LM (2022) Determinants of economic growth across the European Union: a panel data analysis on small and medium enterprises. *Sustainability* 2022 14(8):4797
- Batrancea L (2021) Empirical evidence regarding the impact of economic growth and inflation on economic sentiment and household consumption. *J Risk Financ Manag* 14(7):336
- Batrancea L (2021) The Nexus between Financial Performance and Equilibrium: Empirical Evidence on Publicly Traded Companies from the Global Financial Crisis Up to the COVID-19 Pandemic. *J Risk Financ Manag* 14(5):218
- Batrancea L, Batrancea I, Moscviciov A (2009) The roots of the world financial crisis. *Ann Fac Econ* 3(1):57–62
- Batrancea LM, Nichita A, Balci MA, Akgüller Ö (2023) Empirical investigation on how wellbeing-related infrastructure shapes economic growth: Evidence from the European Union regions. *PLoS ONE* 18(4):e0283277
- Batrancea LM, Nichita A, Cocis A-D (2022) Financial performance and sustainable corporate reputation: empirical evidence from the Airline Business. *Sustainability* 14(20):13567
- Batrancea I, Moscviciov A, Sabau C, Batrancea LM (2013). Banking Crisis: Causes, Characteristics and Solutions. Proceedings of the DIEM 2013 „Scientific Conference on Innovative Approaches to the Contemporary Economic Problems”, Dubrovnik, Croatia, 1–15, ISSN: 1849-3645
- Cao X, Lemmon M, Pan X, Qian M, Tian G (2019) Political promotion, CEO incentives, and the relationship between pay and performance. *Manag Sci* 65(7):2947–2965
- Chan T, Gountas S, Zhang L, Handley B (2016) Western firms' successful and unsuccessful business models in China. *J Bus Res* 69(10):4150–4160
- Chen W (2023) Can low-carbon development force enterprises to make digital transformation? *Bus Strat Environ* 32(4):1292–1307
- Cheng C, Cui H (2024) Combining digital and legacy technologies: firm digital transformation strategies—evidence from Chinese manufacturing companies. *Humanit Soc Sci Commun* 11:1021
- Cheng W, Wu Y (2019) Bank finance for private firms in China: Does political capital still pay off? *World Econ* 42(1):242–267
- Cocis A-D, Batrancea L, Tulai H (2021) The Link between Corporate Reputation and Financial Performance and Equilibrium within the Airline Industry. *Mathematics* 9(17):2150. <https://doi.org/10.3390/math9172150>
- Cui X, Wang C, Liao J, Fang Z, Cheng F (2021) Economic policy uncertainty exposure and corporate innovation investment: Evidence from China. *Pac-Basin Financ J* 67:1–22
- Ding M, He Z, Jia Y, Shen M (2021) State ownership, implicit government guarantees, and crash risk: Evidence from China. *Pac-Basin Financ J* 65:1–28
- Ding M, Suardi S (2019) Government ownership and stock liquidity: Evidence from China. *Emerg Mark Rev* 40:1–22
- Ding X, Guedhami O, Ni Y, Pittman JA (2020) Local and foreign institutional investors, information asymmetries, and state ownership. *Pac-Basin Financ J* 63:1–23
- Eller R, Kronenberg C, Peters M (2023) Digital transformation in small and medium-sized enterprises: business model innovation and information technology adoption—the case of Austria. *Int J Entrep Small Bus* 48(3):318–342
- Fan W, Wu X, He Q (2024) Digitalization drives green transformation of supply chains: a two-stage evolutionary game analysis. *Ann Operat Res* 18:1–20
- Gu L, Ni X, Peng Y, Zhang H (2020) Entry of foreign banks, state ownership, and corporate innovation. *Pac-Basin Financ J* 61:1–15
- Gu X, Cheng X, Zhu Z, Deng X (2021) Economic policy uncertainty and China's growth-at-risk. *Econ Anal Policy* 70:452–467
- Hao Y, Guo Y, Guo Y, Wu H, Ren S (2020) Does outward foreign direct investment (OFDI) affect the home country's environmental quality? The case of China. *Struct Change Econ Dyn* 52:109–119
- Huang Y, Luk P (2020) Measuring economic policy uncertainty in China. *China Econ Rev* 59:1–18
- Huang Y, Swamidass P, Raju DA (2016) The nature of innovation in emerging industries in China: An exploratory study. *J Technol Transf* 41(3):451–468
- Jiang K, Du X, Chen Z (2022) Firms' digitalization and stock price crash risk. *Int Rev Financ Anal* 82:1–16
- Lazić M, Vukmirović V, Banović J, Simović V, Paunović M (2023). Digital competences as a precondition for an inclusive digital economy—is there a gender gap among persons with disabilities in Serbia?. *J Women's Entrep Edu* 51–71
- Li J, Shan Y, Tian G, Hao X (2020) Labor cost, government intervention, and corporate innovation: Evidence from China. *J Corp Financ* 64:1–28
- Li L, Su F, Zhang W, Mao JY (2018) Digital transformation by SME entrepreneurs: A capability perspective. *Inf Syst J* 28(6):1129–1157
- Li S, Song X, Wu H (2015) Political connection, ownership structure, and corporate philanthropy in China: A strategic-political perspective. *J Bus Ethics* 129(2):399–411
- Li X, Xu Q, Guo F, Wang H (2023) State-owned equity participation and private sector enterprises' strategic risk taking: Evidence from China. *Manag Decis Econ* 44(2):1107–1124
- Li Z (2019). *Evaluation of Doing Business in Chinese Cities*. China Development Press (In Chinese)
- Liu Y, Dong Y, Qian W (2024) The impact of digital transformation on the quality and safety level of agricultural exports: evidence from Chinese listed companies. *Human Soc Sci Commun* 11:817
- Liu B, Li M, Ji Z, Li H, Luo J (2024) Intelligent productivity transformation: corporate market demand forecasting with the aid of an AI virtual assistant. *J Organ End Use Comput* 36(1):1–27
- Liu C, Zhang W, Zhu X (2022) Does digital transformation promote enterprise development? Evidence from Chinese A-share listed enterprises. *J Organ End Use Comput* 34(7):1–18
- Ma H, Hao D (2022) Economic policy uncertainty, financial development, and financial constraints: Evidence from China. *Int Rev Econ Financ* 79:368–386
- Ma R, Lin B (2023) Digital infrastructure construction drives green economic transformation: evidence from Chinese cities. *Human Soc Sci Commun* 10(1):1–10
- Matt C, Hess T, Benlian A (2015) Digital transformation strategies. *Bus Inf Syst Eng* 57(5):339–343
- Maung M, Wilson C, Tang X (2016) Political connections and industrial pollution: Evidence based on state ownership and environmental levies in China. *J Bus Ethics* 138(4):649–659
- Moscviciov A, Bătrancea I, Bătrancea M, Bătrancea LM (2010) Financial ratio analysis used in the it enterprises. *Ann Univ Oradea Econ Sci* 19(2):600–603
- Petani FJ, Zaoui I, Kovalev S, Montagnon P (2023) What will (and should) sustainable digital maturity look like in business ecosystems? A Delphi study on the best practices, barriers and regulation of digital transformation. *Int J Entrep Small Bus* 49(1):87–122
- Ren M, Manning S, Vavilov S (2019) Does state ownership really matter? The dynamic alignment of China's resource environment and firm internationalization strategies. *J Int Manag* 25(3):1–17
- Salamzadeh A, Dana LP, Ghaffari Feyzabadi J, Hadizadeh M, Eslahi Fatmesari H (2024) Digital technology as a disentangling force for women entrepreneurs. *World* 5(2):346–364
- Salamzadeh A, Hadizadeh M, Feyzabadi JG, Yasin N, Paramba JN (2025). The role of digital platforms in transforming corporate governance: a path to sustainability through ESG in modern corporate governance strategies for sustainable value creation (pp. 111–136). IGI Global Scientific Publishing
- Sharma RC, Kohli D (2024) Embracing digital transformation for sustainable development: The synergy between learning organizations, human resource management, and service quality. *J Chin Hum Resour Manag* 14(3):3–17
- Song Z, Nahm AY, Zhang Z (2017) Partial state ownership, political connection, and financing: Evidence from Chinese publicly listed private sector enterprises. *Emerg Mark Financ Trade* 53(3):611–628
- Song Z, Nahm A, Zhang Z (2015) The value of partial state ownership in publicly listed private sector enterprises: Evidence from China. *Post-Communist Econ* 27(3):336–353
- Tang X, Tsui S, Lo KT (2024) Local institutional environment and stock price crash risk: Evidence from China. *Singap Econ Rev* 69(06):1955–1976
- Vial G (2019) Understanding digital transformation: a review and a research agenda. *J Strateg Inf Syst* 28(2):118–144
- Wang M, Qiu C, Kong D (2017) Corporate social responsibility, investor behaviors, and stock market returns: Evidence from a natural experiment in China. *J Bus Ethics* 101(1):127–141
- Wang X, Sun J, Tian L, Guo W, Gu T (2021) Environmental dynamism and cooperative innovation: The moderating role of state ownership and institutional development. *J Technol Transf* 46(5):1344–1375
- Wu F, Hu H, Lin H, Ren X (2021) Enterprise digital transformation and capital market performance: Empirical evidence from stock liquidity. *Manag World* 37(7):130–144
- Wu HL (2011) Can minority state ownership influence firm value? Universal and contingency views of its governance effects. *J Bus Res* 64(8):839–845
- Wu S, Cheng P, Yang F (2024) Study on the impact of digital transformation on green competitive advantage: The role of green innovation and government regulation. *PLoS ONE* 19(8):e0306603
- Xu M, Tan R (2024) Digital economy as a catalyst for low-carbon transformation in China: new analytical insights. *Humanit Soc Sci Commun* 11:841
- Yao Y, Chen GS, Salim R, Yu X (2018) Schooling returns for migrant workers in China: Estimations from the perspective of the institutional environment in a rural setting. *China Econ Rev* 51:240–256
- Yu H, Song C, Song Z (2022a) Impact of state ownership as political capital on the technological innovation of private sector enterprises: Evidence from China. *Asian J Technol Innov* 30(1):158–177
- Yu H, Song C, Song Z (2022b). Impact of government ownership on private sector enterprises' environmental responsibility: Empirical evidence from Chinese listed firms. *Int J Emerg Mark*, 1–21

- Zhao S et al. (2024) Enterprise pollution reduction through digital transformation? Evidence from Chinese manufacturing enterprises. *Technol Soc* 77:102520
- Zhao S, Zhang L, An H, Peng L, Zhou H, Hu F (2023) Has China's low-carbon strategy pushed forward the digital transformation of manufacturing enterprises? Evidence from the low-carbon city pilot policy. *Environ Impact Assess Rev* 102:107184
- Zhao S, Zhang L, Peng L, Zhou H, Hu F (2024) Enterprise pollution reduction through digital transformation? Evidence from Chinese manufacturing enterprises. *Technol Soc* 77:102520
- Zhang C, Liu B, Yang Y (2024) Digital economy and urban innovation level: A quasi-natural experiment from the strategy of "Digital China". *Humanit Soc Sci Commun* 11(1):1–12
- Zhang Z, Jin J, Li S, Zhang Y (2023) Digital transformation of incumbent firms from the perspective of portfolios of innovation. *Technol Soc* 72:1–14
- Zhou KZ, Gao GY, Zhao HX (2017) State ownership and firm innovation in China: An integrated view of institutional and efficiency logics. *Adm Sci Q* 62(2):375–404

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Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Competing interests

The author(s) declare no competing interests.

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