The impact of equity structure on technological innovation efficiency in China's listed textile firms

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ABSTRACT – REZUMAT

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Technological innovation efficiency is a pivotal metric for assessing a firm's innovation capability, and equity structure is a key determinant shaping it. This study investigates this relationship within China's listed textile sector (Shanghai and Shenzhen A-share markets, 2013–2024). To isolate the true managerial performance, we employ an integrated three-stage Data Envelopment Analysis (DEA) model that purges the effects of external environmental factors and statistical noise. Subsequently, a Tobit regression is used to test the impacts of distinct equity governance mechanisms. The main findings are: (1) External environmental factors significantly inflate initial efficiency measurements; after purification, the overall decline is primarily driven by reduced pure technical efficiency, highlighting managerial practices as the critical bottleneck. (2) The adjustment reveals divergent paths: state-shareholding firms show improved efficiency mainly through scale efficiency, whereas non-state-shareholding firms exhibit a decline due to deficiencies in pure technical efficiency. (3) Regarding equity structure, ownership concentration, equity checks and balances, and institutional ownership all significantly promote technological innovation efficiency. In contrast, the mere presence of state shareholding exerts no statistically significant direct effect. These findings underscore that internal governance mechanisms, rather than ownership labels, are decisive for driving innovation efficiency in traditional manufacturing industries transforming.

Keywords: *technological innovation efficiency, equity structure, corporate governance, textile industry, listed companies, three-stage DEA, Tobit model*

Impactul structurii capitalului propriu asupra eficienței inovării tehnologice în cadrul companiilor textile cotate la bursă din China

Eficiența inovării tehnologice reprezintă un indicator esențial pentru evaluarea capacității de inovare a unei întreprinderi, iar structura capitalului propriu este un factor determinant cheie care o modelează. Prezentul studiu analizează această relație în cadrul sectorului textil cotat la bursă din China (piețele de acțiuni de tip A din Shanghai și Shenzhen, perioada 2013–2024). Pentru a izola performanța managerială reală, a fost utilizat un model integrat de Data Envelopment Analysis (DEA) în trei etape, care elimină efectele factorilor de mediu externi și ale zgomotului statistic. Ulterior, se utilizează o regresie Tobit pentru a testa impactul diferitelor mecanisme de guvernanță a capitalului propriu. Principalele concluzii sunt: (1) Factorii de mediu externi umflă în mod semnificativ măsurătorile inițiale ale eficienței; după eliminare, scăderea generală este determinată în principal de reducerea eficienței tehnice pure, ceea ce evidențiază practicile manageriale ca fiind principalul obstacol. (2) Ajustarea relevă traiectorii divergente: întreprinderile cu capital de stat prezintă o eficiență îmbunătățită în principal prin eficiența de scară, în timp ce întreprinderile fără capital de stat înregistrează o scădere din cauza deficiențelor în ceea ce privește eficiența tehnică pură. (3) În ceea ce privește structura capitalului propriu, concentrarea proprietății, mecanismele de control și echilibrul acționariatului, precum și deținerea instituțională, acestea promovează în mod semnificativ eficiența inovării tehnologice. În schimb, simpla prezență a acționariatului de stat nu exercită niciun efect direct semnificativ din punct de vedere statistic. Aceste concluzii subliniază faptul că mecanismele interne de guvernanță, mai degrabă decât etichetele de proprietate, sunt decisive pentru stimularea eficienței inovării în industriile manufacturiere tradiționale aflate în plin proces de transformare.

Cuvinte-cheie*: eficiența inovării tehnologice, structura capitalului propriu, guvernanța corporativă, industria textilă, societăți cotate la bursă, DEA în trei etape, modelul Tobit*

INTRODUCTION

China's textile industry, a cornerstone of the national economy, stands at a critical juncture. After decades of rapid expansion fueled by labour-cost advantages, the sector now grapples with the erosion of the "demographic dividend" and rising production costs [1], prompting the relocation of many firms to Southeast Asia. To sustain competitiveness, the industry must transition from factor-driven growth to innovation-led development, a strategic priority underscored by the 2024 Government Work Report and the Action Outline for the Construction of a Modern Textile Industry System (2022–2035).

In the knowledge-based economy, technological innovation efficiency, reflecting a firm's capability to transform R&D inputs into valuable outputs, has become pivotal for maintaining competitive advantage. However, innovation is inherently characterised by long cycles, high risk, and substantial investment, making it particularly susceptible to principal-agent problems arising from the separation of ownership and control [2]. As a fundamental element of corporate governance, equity structure directly shapes incentive alignments and agency costs, thereby critically influencing managerial decisions on innovation resource allocation [3]. Understanding this nexus is essential for unlocking the innovation potential within traditional manufacturing sectors like textiles.

Extant literature offers valuable insights yet remains inconclusive. Debates persist regarding the impact of ownership concentration [4], the moderating role of ownership checks and balances [5], the influence of institutional investors [6], and the effect of state shareholding [7]. Furthermore, a significant methodological gap exists: many studies measuring innovation efficiency fail to adequately account for external environmental factors and statistical noise, potentially leading to biased estimations. This study aims to address these gaps by investigating how equity structure affects the true technological innovation efficiency of China's listed textile firms, after rigorously purging the influence of the operating environment.

To achieve this objective, we employ an integrated empirical framework. First, we apply a three-stage Data Envelopment Analysis (DEA) model to a sample of 60 A-share listed textile companies (2013–2024) to derive innovation efficiency scores net of environmental and random disturbances. Subsequently, we use a Tobit regression model to test our hypotheses concerning the relationships between key equity structure variables, concentration, balance, institutional ownership, and state shareholding, and the adjusted innovation efficiency.

The remainder of this paper is structured as follows. The 2nd section reviews the relevant literature and formally develops the research hypotheses. The 3rd section details the research design, including the specification of the three-stage DEA and Tobit models, variable definitions, and data sources. The 4th section presents the empirical results, comprising the efficiency analysis and regression findings, followed by robustness checks. The 5th section provides an in-depth discussion, comparing the results with existing literature and elucidating the study's theoretical contributions and practical implications. Finally, the 6th section concludes by summarising the key findings, synthesising the managerial and policy insights, and outlining limitations and future research directions. An overview of the entire research framework is visually presented in figure 1 to guide the reader.

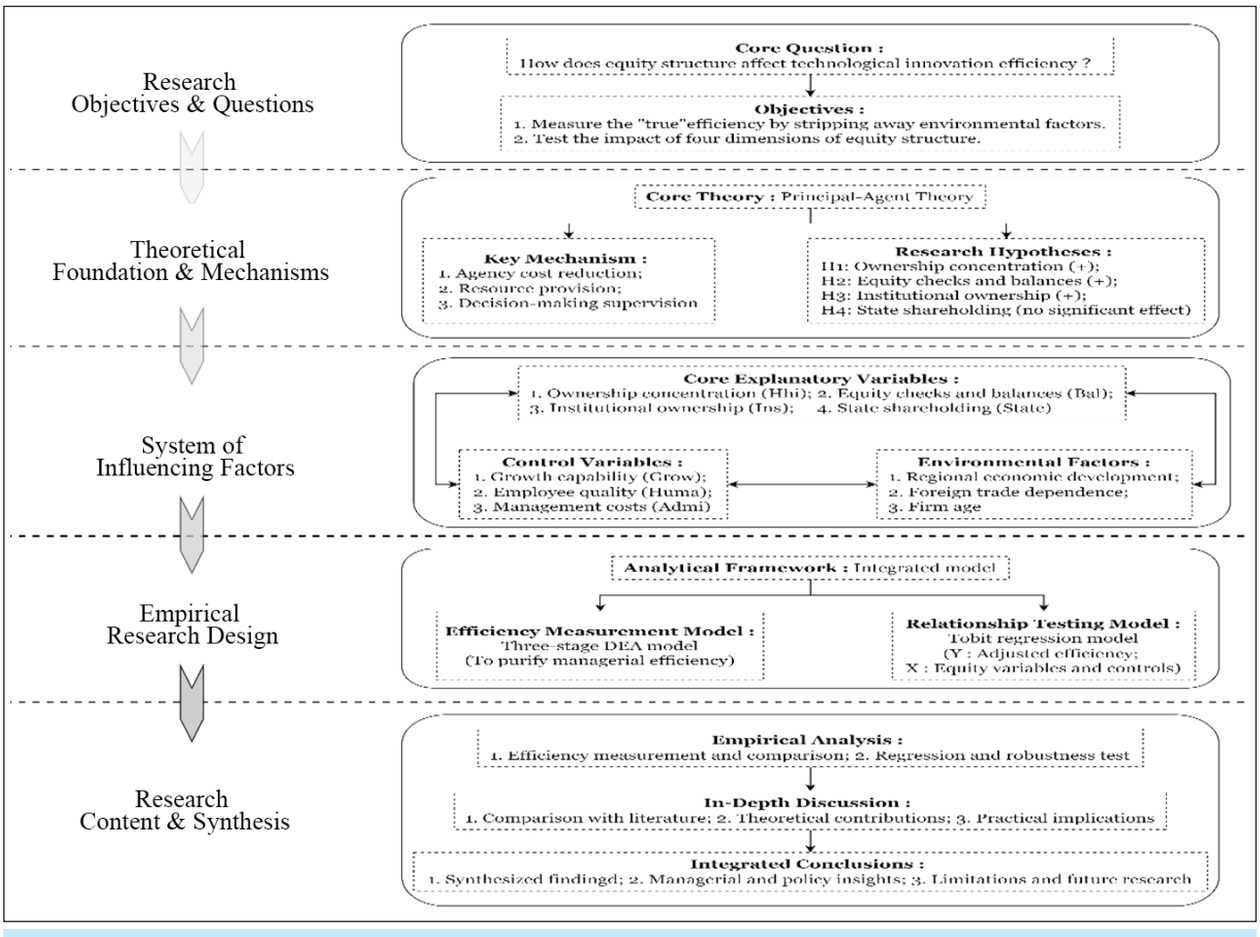


Fig. 1. Research framework

The schematic outlines the conceptual and analytical framework developed for this study.

LITERATURE REVIEW

Technological innovation is the cornerstone for the transformation and upgrading of traditional manufacturing industries. For China's textile sector, which is grappling with the loss of the demographic dividend and rising global competition, improving innovation efficiency is not merely a strategic choice but a necessity for survival and high-quality development [8, 9]. Recent studies continue to highlight the generally low level of green technology [8] and overall technological innovation efficiency [10] within the industry, underscoring the persistent urgency of this issue. At the micro-firm level, innovation efficiency is fundamentally shaped by corporate governance structures, with equity arrangement being a primary determinant [11]. The principal-agent conflict arising from the separation of ownership and management remains a central theoretical lens for understanding innovation decisions [12]. Equity structure influences the intensity of these conflicts and the consequent allocation of resources to long-term, high-risk innovative activities. However, empirical findings on the nature of these relationships are mixed and context-dependent, warranting a focused examination within the specific institutional and industrial setting of China's textile sector.

Ownership concentration and innovation efficiency: a contingent relationship

The impact of ownership concentration on innovation is theoretically ambiguous and empirically contested. Concentrated ownership can mitigate Type I agency problems (manager-shareholder) by enhancing monitoring and aligning interests, potentially fostering a long-term orientation conducive to innovation [13]. Conversely, excessive concentration may lead to Type II agency problems (controlling vs. minority shareholders), where the controlling shareholder expropriates resources or avoids risky innovation to secure private benefits [14].

Recent studies reflect this complexity. Some find a negative or inhibitory effect, suggesting that highly concentrated control may stifle innovation by limiting managerial discretion and promoting risk aversion [10, 15]. Others propose a non-linear, inverted U-shaped relationship, where moderate concentration is optimal [16]. This study posits that, given the relatively dispersed ownership structure prevalent among many listed textile firms in China [10], a higher degree of concentration in the current stage may help overcome managerial short-termism and provide the stable oversight needed for sustained R&D investment. Therefore, we hypothesise that in the context of China's textile industry:

H1: Ownership concentration is positively correlated with technological innovation efficiency.

The governance role of equity checks and balances and institutional investors

Beyond the largest shareholder, the distribution of power among other major shareholders and equity checks and balances plays a critical governance role. A balanced equity structure can restrain the controlling shareholder's self-serving behaviour, protect minority interests, and encourage more transparent, value-maximising decisions, including innovation [17, 18]. Recent evidence strongly supports this view, showing that equity restriction mechanisms significantly promote innovation quality and efficiency by incentivising R&D investment and improving decision-making processes [17, 19].

Institutional investors, with their professional expertise and monitoring capabilities, represent another key governance force. Their involvement can reduce information asymmetry, alleviate managerial myopia, and provide essential resources for innovation [20]. Studies confirm that institutional shareholding, particularly by long-term and independent institutions, improves corporate innovation quality and efficiency through enhanced supervision and resource provision [20, 21]. This is especially relevant for traditional industries like textiles seeking external expertise for upgrading. Thus, we propose:

H2: Equity checks and balances promote technological innovation efficiency in textile enterprises.

H3: Institutional ownership helps improve technological innovation efficiency in textile enterprises.

The evolving role of state shareholding

The impact of state shareholding on innovation is profoundly shaped by institutional transitions. While early literature often highlighted the inefficiencies and political burdens associated with state-shareholding enterprises (SOEs), the ongoing mixed-ownership reform in China has reconfigured this relationship [22]. State shareholding can facilitate access to critical resources, policy support, and long-term capital for innovation, especially in strategic sectors [23]. However, it may also introduce non-commercial objectives and bureaucratic inertia.

Contemporary research suggests that the net effect is increasingly nuanced and may be non-significant in competitive markets. The positive effects of state shareholding are often conditional or mediated by other governance improvements, such as the introduction of heterogeneous blockholders [22] or equity diversification [11]. In the textile industry, which is highly market-oriented, the potential advantages of state backing (e.g., subsidies) may be offset by governance rigidities [8]. Consequently, we expect that in the current market environment:

H4: State shareholding has no significant impact on the technological innovation efficiency of textile enterprises.

Table 1

VARIABLE DESCRIPTION FOR THE THREE-STAGE DEA MODEL			
Category		**Name (unit)**	**Calculation method**
Inputs	Productive	Fixed assets (CNY)	Book value of fixed assets
		Total employees (Persons)	Number of employees at year-end
	Operational	Operating costs (CNY)	Total operating costs
		Accounts receivable (CNY)	Book value of accounts receivable
	R&D	R&D expenditure (CNY)	Total R&D expenditure capitalised and expensed
Outputs	Profitable	Net profit (CNY)	Net profit for the fiscal year
		Operating income (CNY)	Total operating revenue
	Technical	Intangible assets (CNY)	Book value of intangible assets
Environment variables	Internal factors	Shareholding ratio of the largest shareholders (%)	Percentage of shares held by the largest shareholder
		Firm age (Years)	(Observation year – establishment year) + 1
	External factors	Regional GDP per capita (CNY)	GDP per capita of the province where the company is registered
		Regional trade dependence (%)	(Total imports + exports) / GDP of the Company's region

Note: Variable definitions are constructed based on the innovation input-output framework and prior studies [10]. Data sources for these variables are detailed in the 3rd section.

Methodological advancements: isolating managerial efficiency

Accurately measuring technological innovation efficiency is crucial for valid inference. Traditional single-stage DEA models are often criticised for conflating managerial inefficiency with the effects of external environmental factors and statistical noise. The three-stage DEA model addresses this by using Stochastic Frontier Analysis (SFA) to strip away these exogenous influences, yielding a purer measure of managerial performance [24]. This method has gained traction in efficiency analysis across sectors, including energy [25] and, pertinently, textile innovation [10]. Its application ensures that the subsequently analysed relationship between equity structure and innovation efficiency is not confounded by regional disparities, macroeconomic conditions, or random shocks.

Synthesis and research positioning

In summary, while the literature establishes a clear link between equity governance and innovation, the specific mechanisms and outcomes within China's textile industry require further empirical clarification. Recent studies provide updated evidence and more sophisticated methodological tools. This study aims to contribute by: (1) applying the rigorous three-stage DEA model to isolate the true innovation efficiency of listed textile firms; and (2) employing a Tobit regression analysis to empirically test the four hypotheses concerning equity structure, thereby providing contemporary evidence grounded in the industry's specific context.

RESEARCH DESIGN

Three-stage DEA model variables

This study focuses on the micro-level technological innovation efficiency of enterprises. Inputs are categorised into productive inputs, operational inputs, and R&D inputs. Outputs are similarly divided into profit-oriented outputs and technology-oriented outputs. Under the premise of satisfying the "separability assumption", environmental influencing factors were selected from both internal and external aspects. A detailed description of each indicator is provided in table 1.

Tobit model and its variables

Technological innovation is characterised by long cycles, substantial investment, and high risk, resulting in a lagged effect of R&D investment. To capture this dynamic, we construct a one-period lagged Tobit model (Model 1), with the three-stage DEA-measured innovation efficiency of listed textile firms as the dependent variable and its one-period lagged value as an independent variable. To validate the suitability of the explanatory and control variables, using ownership concentration as an example, two additional Tobit models (Models 2 and 3) are established. Based on the validation outcomes from these models, we formulate the final multivariate linear regression Tobit model with a one-period lagged dependent variable (Model 4). β_1^T

$$Effect_{it} = \beta_0 + \beta_1^T Effect_{it-1} + \varepsilon_{it} \quad (1)$$

$$Effect_{it} = \beta_0 + \beta_1^T Effect_{it-1} + \beta_2^T Hhi_{it} + \varepsilon_{it} \quad (2)$$

$$Effect_{it} = \beta_0 + \beta_1^T Effect_{it-1} + \beta_2^T Hhi_{it} + \\ + \beta_m^T Controls_{it} + \varepsilon_{it} \quad (3)$$

Table 2

VARIABLE DEFINITIONS FOR THE TOBIT MODEL			
Type	**Name**	**Symbol**	**Measurement / Definition**
Dependent variable	Technological innovation efficiency	Effect	Efficiency score derived from the three-stage DEA model
Independent variables	Ownership concentration	Hhi	Sum of the squared shareholding of the top five shareholders
	Equity checks and balances	Bal	Sum of shareholding percentages of the 2ndto the10th largest shareholders
	Institutional ownership	Ins	Total shareholding percentage of funds, brokers, insurers and QFIIs
	State shareholding (Dummy)	state	A dummy variable that equals 1 if the firm has state-owned shareholders, and 0 otherwise
Control variables	Growth capability	Grow	Year-on-year growth rate of operating revenue
	Employee quality	Huma	Percentage of employees with a college degree or above
	Management costs	Admi	Ratio of administrative expenses to total operating revenue

Note: See table 1 for input-output variable definitions. The construction of governance and control variables follows common practices in corporate finance literature. Data sources are provided in the 3rd section.

$$Effect_{it} = \beta_0 + \beta_1^T Effect_{it-1} + \beta_n^T Explanation_{it} + \\ + \beta_m^T Controls_{it} + \varepsilon_{it} \quad (4)$$

This study primarily examines the impact of equity structure on technological innovation efficiency from the perspective of internal corporate governance. The explanatory and control variables are as detailed in table 2.

Data sources and processing

This study focuses on listed companies in the textile industry in the Shanghai and Shenzhen A-share markets from 2013 to 2024. This period was selected to capture the dynamic changes in the technological innovation efficiency of the textile industry amid the disappearance of the "demographic dividend" and evolving global economic conditions. Despite the limited sample size, we believe that the data from this period accurately reflect the technological innovation efficiency of the listed companies in the textile industry. After the screening process, we identified 60 sample companies that met the criteria. Input and output indicator data are sourced from the Choice database, whereas data on environmental variables came from the annual reports of listed companies, the National Bureau of Statistics, and the statistical bureau websites of various provinces. Data processing for the three-stage DEA model was conducted using DEAP 2.1 and Frontier 4.1, whereas processing for the Tobit model was performed using Stata 17.0.

EMPIRICAL RESULTS

Three-stage DEA model results

Prior to applying the three-stage DEA model, we conducted a statistical description and Pearson correlation test on the model indicators. The tests confirmed that all indicators meet the required criteria, allowing further construction of the DEA model.

Using DEAP 2.1 and the DEA-BCC model, comprehensive efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) were calculated for the 60 listed companies in the textile industry for each year. The annual industry average values were calculated, and the efficiency values from the first-stage DEA-BCC model are presented in figure 2, *a*. Using the adjusted input variables from the second stage alongside the original output variable data, the DEA-BCC model was reapplied to recalculate TE, PTE, and SE for listed companies in the textile industry, excluding environmental factors. The results are presented in figure 2, *b*.

Based on the results presented in figure 2, *a* and *b*, the following conclusions can be drawn.

Technological innovation efficiency is a comprehensive indicator reflecting a firm's ability to utilise and transform relevant resources. From 2013 to 2024, the TE of listed textile companies averaged 0.9, showing a fluctuating downward trend. The PTE ranged between 0.899 and 0.957, with an overall mean of 0.928, while SE fluctuated between 0.925 and 0.989, averaging 0.968, indicating that SE values were generally higher than PTE. Companies with state shareholding had an average innovation efficiency of 0.893, compared to 0.902 for those without, suggesting no significant difference in TE, PTE, or SE between the two, preliminarily supporting the hypothesis that state shareholding does not significantly affect innovation efficiency in this sector. However, as these initial results included the influence of random noise and environmental factors, a second-stage SFA was employed to mitigate these exogenous influences. After adjustment, the TE, PTE, and SE all decreased compared to the first-stage results, indicating that innovation efficiency had been previously overestimated due to external environmental factors. During 2013–2024, the TE fluctuated between 0.845 and 0.96, generally declining after an initial upward trend. The TE peaked in 2016,

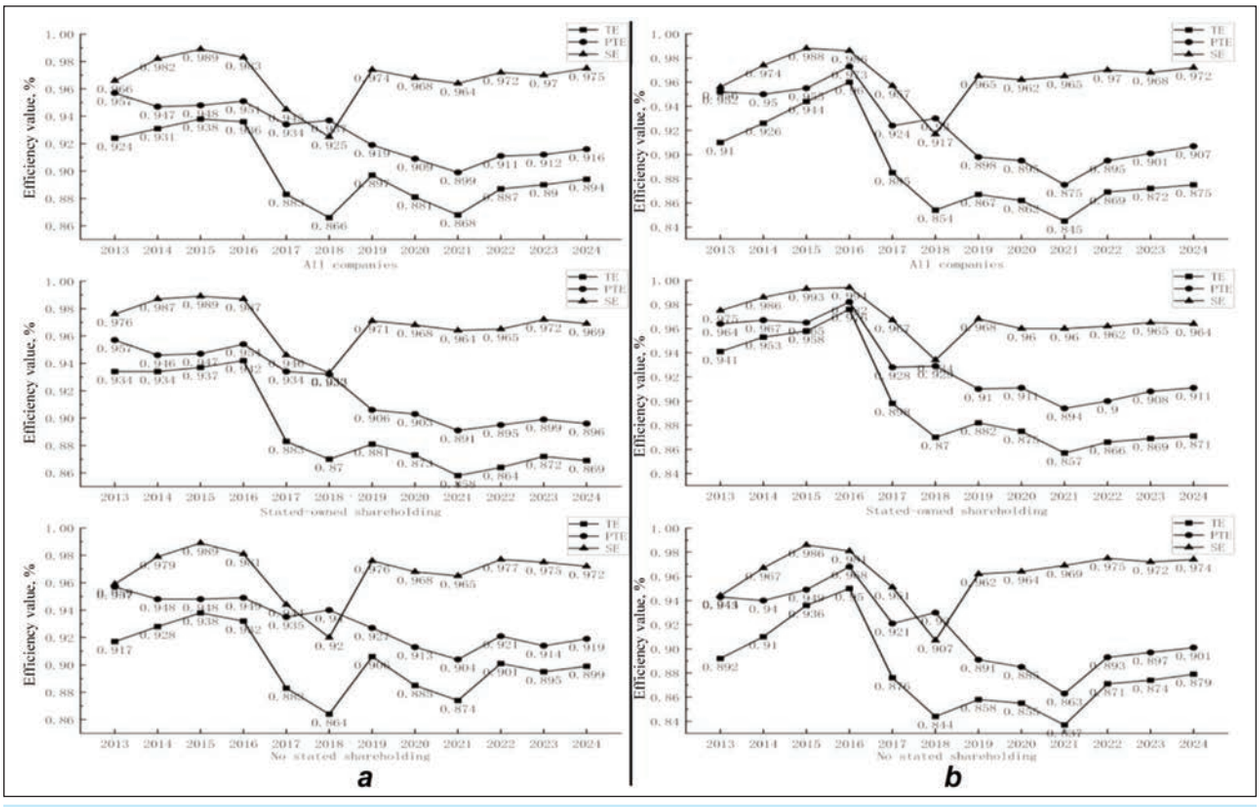


Fig. 2. Average technological innovation efficiency over the years:
a – the first-stage DEA-BCC model; *b* – the second-stage DEA-BCC model

later declining due to national supply-side reforms and Sino-U.S. trade disputes, rebounded briefly in 2018, and fell again during the COVID-19 pandemic. After controlling for environmental factors, innovation efficiency in firms with state shareholding improved, primarily driven by increased SE, with a slight rise in PTE, suggesting that adverse external conditions had previously constrained their efficiency. In contrast, firms without state shareholding showed a significant decline in innovation efficiency, mainly due to reduced PTE, indicating that their efficiency had been overestimated before environmental adjustments.

Tobit model results

Descriptive statistics were obtained for each explanatory variable included in the Tobit model. To avoid multicollinearity, testing revealed that the variance inflation factor (VIF) values for all explanatory variables are less than 5, confirming the absence of multicollinearity in the model, which does not affect the accuracy of the regression results.

In the Tobit model analysis, Model (1) is used to verify the effect of one-period lagged technological innovation efficiency on current technological innovation efficiency. Models (2) and (3) are used to test the suitability of the explanatory and control variables in the Tobit model with a one-period lagged dependent variable, using ownership concentration as the explanatory variable example.

From table 3, it can be seen that Model (1) provides strong evidence that one-period lagged technological innovation efficiency has a positive impact on current technological innovation efficiency. This finding indicates that the technological innovation of listed

Table 3

REGRESSION RESULTS OF MODELS (1), (2), AND (3)

Variable	Hhi	Effect$_{it-1}$	Grow	Huma	Admi	_cons	Sigma_U	Sigma_E	N	Rho
Model (1)		0.815*** (15.907)				18.227*** (3.931)	4.207*** (5.403)	7.677*** (25.821)	660	0.231
Model (2)	0.125*** (2.677)	0.781*** (15.137)				19.069*** (4.230)	4.666*** (5.737)	7.533*** (25.593)	660	0.277
Model (3)	0.122** (2.630)	0.756*** (14.949)	0.032* (1.771)	0.075** (2.539)	–0.388** (–2.416)	22.271*** (4.604)	4.648*** (5.847)	7.408*** (25.522)	660	0.282

Note: Regression results are based on the authors' calculations using Tobit models. Data sources are provided in the 3rd section. ***, **, and * indicate that the model regression coefficients are significant at the 1%, 5%, and 10% significance levels, respectively. Z values corresponding to the regression coefficients are in parentheses.

companies in the textile industry has a lag effect and that the lag of the dependent variable should be considered when constructing the Tobit multivariate linear model. Moreover, the regression results from Models (2) and (3), which include a one-period lagged dependent variable, show that both explanatory and control variables are significant. This suggests that the Tobit model established in this paper, which includes a one-period lagged dependent variable, is robust and can effectively explain the factors affecting technological innovation efficiency.

By constructing a Tobit multivariate linear regression model with a one-period lagged dependent variable, this work explores the impact of equity structure on corporate technological innovation efficiency. This study controls for growth capability, employee quality, and management costs. The model's regression results are presented in table 4.

Based on the empirical results, ownership concentration, equity checks and balances, and institutional ownership all demonstrate significant positive effects on the technological innovation efficiency of listed textile companies, supporting H1, H2, and H3. Higher ownership concentration helps alleviate principal-agent conflicts, incentivises firms to increase R&D investment, and positively impacts innovation efficiency. This conclusion reflects that, among the sampled textile firms, moderate ownership concentration effectively mitigates agency conflicts between shareholders and management, creating a stable environment conducive to long-term R&D investment. This finding resonates with recent studies suggesting that ownership concentration can exert a positive monitoring effect under specific circumstances [10, 16]. Stronger equity checks and balances can constrain the controlling power of the largest shareholder and mitigate conflicts of interest among shareholders, thereby enhancing innovation efficiency. This suggests that effective oversight by other major shareholders over the controlling shareholder can curb potential expropriation behaviours and safeguard corporate resources allocated for innovation. This finding aligns with the current literature asserting that equity constraints can improve innovation quality by strengthening corporate governance [17, 19].

Moreover, Institutional investors further promote corporate innovation by providing financial support, professional expertise, and market-oriented strategic guidance–particularly valuable for traditional manufacturing sectors like textiles, which rely on innovation-driven transformation and upgrading. Recent studies also highlight the dual role of institutional

Table 4

REGRESSION RESULTS OF MODEL (4)

Variable	Model (4-1)	Model (4-2)	Model (4-3)	Model (4-4)	Model (4-5)	Model (4-6)
Hhi	0.122** (2.630)	0.122** (2.635)				
Hhi×State		–0.009 (–0.151)				
Bal			0.116** (2.726)	0.123*** (2.844)		
Bal×State				–0.051 (–1.415)		
Ins					0.262** (2.095)	0.264** (2.112)
Ins×State						–0.041 (–1.137)
$Effect_{it-1}$	0.756*** (14.949)	0.757*** (14.916)	0.772*** (15.562)	0.773*** (15.657)	0.790*** (15.624)	0.793*** (15.708)
Grow	0.032* (1.771)	0.032* (1.758)	0.028 (1.513)	0.026 (1.450)	0.026 (1.377)	0.025 (1.337)
Huma	0.075** (2.539)	0.076** (2.540)	0.076** (2.644)	0.079*** (2.726)	0.066** (2.293)	0.068** (2.356)
Admi	–0.388** (–2.416)	–0.391** (–2.417)	–0.413** (–2.621)	–0.429*** (–2.724)	–0.405** (–2.545)	–0.416** (–2.623)
_cons	22.271*** (4.604)	22.277*** (4.606)	20.077*** (4.162)	20.278*** (4.242)	21.232*** (4.202)	21.385*** (4.254)
Sigma_U	4.648*** (5.847)	4.640*** (5.826)	4.159*** (5.569)	4.222*** (5.640)	4.128*** (5.345)	4.154*** (5.389)
Sigma_E	7.408*** (25.522)	7.408*** (25.520)	7.484*** (25.771)	7.459*** (25.777)	7.524*** (25.700)	7.510*** (25.713)
N	660	660	660	660	660	660
Rho	0.282	0.282	0.236	0.243	0.231	0.234

Note: Data sources and variable symbols are consistent with those described in table 3.

investors in enhancing corporate innovation quality through both governance oversight and resource provision [20, 21].

In contrast, state shareholding shows no statistically significant impact on technological innovation efficiency, which aligns with H4. Although state involvement may offer advantages such as policy support and resource allocation, it may also introduce social responsibilities and administrative burdens that offset potential innovation benefits. This, to some extent, corroborates the academic observation that, under the current context of mixed-ownership reform, the direct impact of ownership type itself has become increasingly complex [11, 22]. Additionally, other control variables, including growth capability and employee quality, show positive correlations with innovation efficiency, whereas management costs exhibit a significant negative relationship. This suggests that stronger development capacity, higher human capital, and reduced administrative friction all contribute to enhanced innovation performance.

Robustness tests

To enhance the reliability of the empirical findings, this study conducted the following robustness checks: (1) Sample period adjustment. To mitigate potential short-term effects from the 2019 U.S.–China trade friction and the 2020 COVID-19 pandemic, the model was re-estimated by excluding data from 2019, 2020, or both. The results show that the coefficients and significance levels of the core equity structure variables remain consistent with the baseline model. (2) Subsample analysis. Considering regional disparities in economic development and policy support, firms headquartered in central and western regions were excluded. Regression results using the subsample of firms from the eastern region confirm the stability of the key explanatory variables in both sign and statistical significance. (3) Sensitivity analysis. The robustness of the main explanatory variable – ownership concentration (Hhi) – was tested by applying a ±10% variation to its measurement. Additional checks include altering model specifications by introducing or omitting other potential control variables, such as firm size and market competition intensity. The positive relationship between ownership concentration and technological innovation efficiency remained robust throughout these tests.

DISCUSSION

This section provides a comprehensive interpretation of the empirical findings, positioning them within the broader scholarly conversation on corporate governance and innovation. We first compare and contrast our results with existing literature, then elucidate the specific theoretical contributions of this study, and finally summarise its practical implications, which are detailed in the subsequent chapter.

Comparative analysis with existing literature

Our findings offer nuanced confirmations and extensions to the ongoing debate on how equity structure shapes corporate innovation.

Regarding ownership concentration, our results demonstrate a significant positive linear relationship with technological innovation efficiency. This aligns with the view that concentrated ownership can mitigate Type I agency problems by enhancing monitoring and incentivising long-term R&D investment [13]. However, it appears to contrast with studies proposing an inverted U-shaped relationship [16], where excessive concentration becomes detrimental. This divergence may be context-specific. For the listed textile firms in our sample, characterised by relatively dispersed ownership and facing intense transformation pressure, a higher degree of concentration may not yet have reached the threshold where entrenchment and expropriation (Type II agency problems) outweigh its monitoring benefits. Thus, our finding likely captures the upward-sloping segment of the curve, highlighting that the optimal ownership structure is contingent on industry dynamics and initial governance conditions.

Concerning equity checks and balances and institutional ownership, our results strongly corroborate recent empirical work. The positive effect of equity checks and balances supports the argument that restraining the controlling shareholder's power protects innovation resources and fosters more balanced decision-making [17, 19]. Similarly, the positive role of institutional ownership resonates with literature emphasising their dual function of providing superior monitoring and valuable external resources, which are particularly crucial for innovation in traditional industries [20, 21]. Our study reinforces that these governance mechanisms are effective not only in high-tech sectors but also in traditional manufacturing like textiles, where upgrading depends critically on efficient resource use and external knowledge.

The most striking finding pertains to state shareholding. The statistically insignificant coefficient for State aligns with an emerging strand of literature that questions the deterministic role of formal ownership type in a competitive market [7, 22]. While traditional views posited clear advantages (e.g., resource access) or disadvantages (e.g., bureaucratic inertia) for state-shareholding enterprises, our result suggests a more complex reality shaped by China's mixed-ownership reforms. The insignificance may indicate that the presence of state capital is less impactful than the governance quality and commercial orientation it is embedded within. Potential benefits (e.g., policy support) and costs (e.g., social objectives) may offset each other, making internal governance mechanisms like ownership concentration and equity checks and balances more salient determinants of innovation efficiency. This finding shifts the focus from a binary "state vs. private" debate to a more granular analysis of governance arrangements within different ownership forms.

Theoretical contributions

This study makes several distinct contributions to the theoretical discourse on corporate governance and innovation.

First, it advances methodological rigour in measuring the dependent variable. By employing the three-stage DEA model to purge environmental and statistical noise from the innovation efficiency scores, we provide a cleaner test of governance theories. Much of the prior ambiguity in the literature may stem from the conflation of managerial inefficiency with external factors. Our approach isolates the "managerial" component of efficiency, thereby offering a more precise estimate of how internal governance mechanisms, such as equity structure, actually influence a firm's capacity to transform inputs into innovative outputs.

Second, it contextualises and enriches principal-agent and resource-based theories. The results demonstrate that classic agency theory retains strong explanatory power in a traditional industry setting, but its manifestations are nuanced. The positive effects of both ownership concentration (addressing manager-shareholder conflicts) and equity checks and balances (addressing shareholder-shareholder conflicts) confirm the multi-faceted nature of agency problems in innovation. Furthermore, the positive role of institutional ownership integrates the resource-based view, highlighting that certain shareholders are not just monitors but also vital sources of information and expertise. Our study thus presents a more integrated theoretical framework where governance structures simultaneously mitigate agency costs and facilitate resource provision to drive innovation efficiency.

Third, it deepens the understanding of ownership reform in transitional economies. The non-significant finding for state shareholding, coupled with the significant results for other governance variables, contributes to the literature on China's mixed-ownership reforms. It suggests that reform efforts should look beyond mere changes in ownership labels and focus intensively on cultivating high-quality, professional, and balanced internal governance mechanisms. The theoretical implication is that governance quality mediates the relationship between ownership type and firm outcomes like innovation.

Implications for practice

The findings translate into clear directives for corporate managers, investors, and policymakers, which are elaborated in detail in the 6th section. In essence, they collectively argue for a shift in focus:

For boards and controlling shareholders. Prioritise the construction of an effective internal equity governance mix, balancing appropriate concentration with checks and balances and attracting long-term institutional investors, over reliance on ownership type alone.

For policymakers. Design support mechanisms that incentivise good internal governance practices and innovation management efficiency, rather than favouring firms based solely on ownership. Fostering industry-level collaborative platforms can help diffuse best practices, especially among non-state-shareholding firms.

This discussion synthesises how our context-specific empirical results refine theoretical expectations and guide actionable strategies. The following conclusion chapter will now integrate these insights into a final, overarching synthesis.

CONCLUSIONS AND IMPLICATIONS

Synthesised conclusions and scholarly contribution

This study rigorously examines the nexus between corporate governance and innovation productivity in a traditional yet vital industry. By applying a three-stage DEA model to strip away environmental distortions, we reveal the "true" managerial efficiency in technological innovation among China's listed textile firms. The central conclusion is that internal equity governance mechanisms exert a more decisive influence on innovation efficiency than external ownership labels. Specifically, we conclude that:

First, governance efficacy over ownership form. While ownership concentration, equity checks and balances, and institutional ownership are all significant positive drivers, the mere presence of state shareholding is not. This underscores that how ownership is structured and exercised (governance) is more critical than who owns it (ownership nature) in fostering innovation efficiency within a competitive market environment.

Second, the primacy of managerial practices. The post-adjustment decline in efficiency, primarily attributed to pure technical inefficiency, points to internal management and resource allocation processes, rather than scale or external factors, as the key bottleneck. This shifts the focus for improvement from seeking external advantages to optimising internal innovation management systems.

Third, contextualised understanding of equity roles. The findings contribute to a more nuanced theoretical understanding. They suggest that in industries undergoing pressured transformation like textiles, concentrated ownership can provide necessary commitment, while balanced ownership and professional institutional investors introduce essential oversight and expertise. This context-dependent efficacy enriches principal-agent theory and resource-based views in a specific industrial setting.

These conclusions collectively advance the theoretical discourse by demonstrating that established governance theories hold significant explanatory power in traditional sectors, provided the measurement of the dependent variable (technological innovation efficiency) is purified, and the institutional context is carefully considered.

Integrated managerial and policy implications

The preceding conclusions translate into direct implications for practice, forming a bridge from theoretical insight to actionable strategy. These implications are

structured to guide different stakeholders in the innovation ecosystem.

(1) Strategic and governance-level implications for innovation

The findings offer actionable insights for corporate owners and governors to architect an equity structure and incentive system that catalyses innovation.

First, design dynamic equity governance for long-term innovation. Merely adjusting the level of ownership concentration is insufficient. Governance bodies should focus on cultivating a high-quality equity mix. This involves actively introducing long-term-oriented institutional investors (e.g., technology-focused funds, ESG investors) who can provide not only capital but also strategic oversight and market access, aligning with their positive role identified in this study. Furthermore, in line with the ongoing mixed-ownership reform trends, firms, especially state-shareholding ones, should consider diversifying their shareholder base with heterogeneous blockholders from complementary industries (e.g., new materials, digital platforms). This can inject fresh perspectives and mitigate the risk of strategic myopia, directly addressing the core agency problem in innovation investment.

Second, implement innovation-aligned incentives with ESG and digital metrics. To counteract managerial short-termism, compensation committees must move beyond traditional financial metrics. A portion of long-term incentives (e.g., restricted stock units) for executives and R&D leaders should be explicitly tied to innovation output quality and sustainability. Metrics should include the green attributes of patents (e.g., energy-saving processes, recyclable materials), linking managerial rewards directly to the firm's ESG performance and sustainable transition. Concurrently, firms should invest in digital R&D management platforms to track project milestones and resource efficiency in real-time. This data-driven approach not only improves "pure technical efficiency" but also provides transparent, objective bases for incentive payouts, operationalising the potential of digital technology for governance and knowledge management.

(2) Operational and policy-level implications for ecosystem development

The results also provide guidance for internal process optimisation and the design of industry-level innovation policies.

First, streamline internal processes with a focus on green and digital transformation. To elevate pure technical efficiency, firms must scrutinise and re-engineer their innovation value chains. A critical step is establishing dedicated "green innovation" pipelines with streamlined approval processes and cross-functional teams. Additionally, reducing administrative friction ("management costs") requires leveraging digital collaborative tools to automate reporting and facilitate communication between R&D, production, and marketing, thereby enhancing the fluidity of ideas and resources.

Second, fostering an enabling external innovation ecosystem. Policymakers should transition from blanket subsidies to efficiency-based and mission-oriented support. Public funding (e.g., R&D subsidies, innovation funds) could be partially allocated through matching mechanisms that favour firms with higher adjusted innovation efficiency, thus rewarding effective governance and management.

Furthermore, to help the entire industry overcome technological bottlenecks and improve scale efficiency, governments and industry associations should spearhead the creation of shared "Textile 4.0" innovation infrastructures. These could include open-access labs for circular economy technologies, industry cloud platforms for supply chain data pooling, and skill-building programs in AI and data analytics for textile engineers. Such ecosystems lower the innovation threshold for SMEs and foster spillover effects, addressing the industry-wide efficiency challenges highlighted in this study.

Limitations and trajectory for future research

Recognising the boundaries of this study not only clarifies its scope but also illuminates productive paths for further inquiry. The main limitations, and the research opportunities they unveil, are threefold.

First, regarding methodological scope. The three-stage DEA model, while effective in purging environmental noise, is inherently static and non-parametric. Our analysis captures efficiency at specific points in time but does not fully model the dynamic adjustment processes of innovation activities. Future studies could employ dynamic DEA models, panel vector autoregression (PVAR), or system dynamics simulation to explore how equity structure influences innovation efficiency trajectories and the feedback effects over time.

Second, concerning the research context and variables. Our focus was on traditional dimensions of equity structure. However, the modern business environment introduces new, interactive governance factors. For instance, how digital transformation level or ESG (Environmental, Social, and Governance) commitments moderate the identified relationships remains an open question. The rise of hybrid ownership forms, including equity participation by core customers or supply chain partners, also warrants investigation. Furthermore, extending the analysis from firm-level to intra-firm levels (e.g., the efficiency of specific R&D projects) or inter-firm levels (e.g., innovation efficiency within textile industry clusters or supply networks) could yield richer insights.

Third, about the industry sample. Although concentrating on the textile industry enhances internal validity, it may limit the generalizability of our findings to other sectors with different technological regimes (e.g., high-tech or service industries). Comparative studies across multiple traditional manufacturing industries would help distinguish industry-specific effects from universal governance principles.

In conclusion, addressing these limitations would not only validate and extend our findings but also contribute to a more nuanced and comprehensive understanding of corporate governance and innovation management in the era of industrial upgrading and sustainable development.

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