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Research article

A meta-analysis of the causal interpretation of enterprise green innovation: A structural theoretical model

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ABSTRACT

The escalating environmental challenges have compelled corporations to embark on green innovation initiatives, establishing this as a pivotal strategy for attaining economic sustainability. Yet, there remains a lack of consensus within the scholarly community regarding the precursors and outcomes of green innovation. This research leverages Giddens' structuration theory and employs meta-analytical methods to elucidate the determinants and effects of corporate green innovation. Initially, the study synthesizes 288 effect sizes from 161 distinct scholarly articles, spanning from 2012 to early 2023, guided by the structuration framework. This comprehensive analysis corroborates the influence of several structuration theory antecedents on green innovation, thereby offering fresh empirical backing for the theory. Subsequently, it scrutinizes the link between green innovation and its impacts, evaluated through economic and environmental performance lenses. Furthermore, the research contrasts the meta-analytical findings across large-scale and smaller enterprises, underscoring notable disparities in the dynamics of green innovation across different organizational contexts. This inquiry not only reaffirms the theoretical constructs of structuration theory, such as spatialization, subjectification, and structuration, but also integrates these notions with quantifiable variable models. The paper posits that structuration theory could underpin a theoretical framework for dissecting the influential variables associated with green innovation, thereby fostering further academic investigation into corporate environmental innovation.

1. Introduction

Amidst rapid economic expansion and increasing demographic pressures, environmental predicaments such as resource depletion, pollution, and climate change are intensifying. The dichotomy between economic proliferation and environmental stewardship is becoming more pronounced, illuminating the imperative for green economic strategies across all societal segments [1]. In particular, while social advancement and resource characteristics may underpin economic prosperity, they concurrently pose potential detriments to environmental integrity. Green innovation, underpinned by the tenets of environmental conservation and sustainable progress [2], emerges as a pivotal solution to reconcile the discord between economic augmentation and ecological safeguarding [3], aiming to curtail resource consumption, mitigate adverse environmental impacts, and enhance economic dividends. Contemporary research suggests that conventional innovation paradigms frequently regard the environment as a limitless reservoir, emphasizing

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unabated growth and profit maximization. In contrast, green innovation advocates for a reallocation of resources, prioritizing environmental preservation and sustainable development as the linchpins of economic advancement, thus advocating for a harmonious balance between economic and environmental objectives [4]. Additionally, green innovation endeavors to reconfigure social frameworks by bolstering environmental legislation, establishing green benchmarks, certification protocols, and other mechanisms to steer entities towards effective pollution management, resource conservation, and heightened ecological consciousness [5]. This paradigm shift not only accentuates the importance of environmental stewardship but also propels societies towards a more sustainable trajectory, fostering a synergistic relationship between economic development and environmental preservation. Current research on green innovation primarily focuses on its influencing factors, categorization of indicators, and implementation efficiency [2,3]. However, under the predominance of economic theories, research on the factors affecting corporate green innovation lacks standardization, with the selection of factors largely derived from existing literature without theoretical guidance. Against this backdrop, our study recognizes the critical role of theoretical underpinnings in examining the factors impacting corporate green innovation. Therefore, this research aims to bridge this gap by integrating a structured theoretical framework to systematically explore various factors influencing corporate green innovation. The study will concentrate on the relationship between theoretically guided factors and corporate green innovation, with businesses serving as the principal subjects of research.

Amid the burgeoning corpus of literature on green innovation, there persists a notable schism in the empirical understanding of the determinants affecting green innovation and its correlation with economic and environmental outcomes. The extant scholarly dialogue remains fragmented, failing to conclusively reconcile these divergent perspectives. For example, some investigations posit that organizations with heightened absorptive capacities significantly outperform their counterparts in green innovation endeavors, evidenced by correlation coefficients surpassing the 0.5 threshold [6,7]. Yet, this finding is contested by other studies presenting considerably lesser correlation indices, engendering a debate over the consistent influence of absorptive capacity on green innovation [8,9]. Furthermore, the role of governmental environmental mandates in fostering corporate green innovation has been underscored, though the relationship is complex and nuanced [10,11]. Contrary to a linear interpretation, some research advocates for a threshold hypothesis, suggesting that the nexus between environmental regulations and green innovation assumes a non-linear trajectory, characterized by critical inflection points contingent upon temporal, geographical, and situational contexts. When these regulatory measures reach a pivotal threshold, they ostensibly bolster green innovation, thus delineating a nuanced moderate correlation [12,13]. Additionally, there is an observable deficiency in the comprehensive integration of various determinants shaping green innovation within quantitative inquiries. Individual studies may scrutinize the effects of institutional frameworks, resource endowments, and additional factors on green innovation in isolation [14,15], yet they frequently fall short of offering a cohesive analytical synthesis. Giddens' theory of structuration provides a conceptual framework to understand how social structures, articulated through resources and norms, shape individual and collective actions within given temporal and spatial bounds [16]. In light of these considerations, a meta-analytical approach could potentially illuminate the multifaceted impacts exerted by diverse variables on green innovation. By amalgamating empirical studies in this domain, one can mitigate statistical discrepancies stemming from heterogeneous factors, thereby enriching the academic discourse and facilitating a more comprehensive comprehension of green innovation's dynamics and its influencing elements.

The objective of this study is to employ Giddens' theory of structuration to investigate the complex interrelations between various determinants of green innovation within corporate settings. By utilizing a meta-analytical approach, this research aims to consolidate existing empirical studies, addressing the inconsistencies and enhancing our understanding of green innovation's dynamics. This leads to the formulation of our primary research questions:

What are the key determinants influencing green innovation within corporate settings, and how do these determinants interrelate?

How does the relationship between governmental environmental mandates and corporate green innovation unfold across different contexts and conditions?

In what ways do organizational attributes, such as absorptive capacity, impact the effectiveness of green innovation initiatives?

This research will leverage a comprehensive dataset of 161 empirical studies to conduct a thorough meta-analysis, evaluating factors influencing green innovation and addressing publication bias and heterogeneity among studies. The outcomes of this research are anticipated to offer valuable recommendations for both theoretical development and practical application in the realm of green innovation, especially for policymakers engaged in crafting effective green innovation strategies.

2. Theoretical foundation and literature review

2.1. Research on theory of structuration and its related components

In Giddens' theory of structuration, time and space are delineated as fundamental dimensions shaping social action [17]. Consequently, businesses are compelled to engage in perpetual learning and assimilation of cutting-edge green innovation technologies, ensuring the continuous evolution of green innovation concepts within designated temporal frameworks. Moreover, the geographical positioning significantly affects a company's ability to internalize green innovation insights. Specifically, entities located in regions renowned for advanced green innovation have the advantage of easier access to the latest knowledge and technological advancements, enabling rapid integration and application to their operations [18,19]. Subject energy emphasizes the role of individual initiative and agency, suggesting that societal structures are molded through the interactions of its constituents [17]. The research and development endeavors and the green strategic focus of a company are closely tied to this subject energy. Additionally, a firm's green strategic orientation delineates its chosen trajectory, facilitating the acquisition of competitive edges in the marketplace and fostering sectoral transformation and enhancement [20].

Resources are pivotal within the theoretical construct of structuration. Their allocation, management, and deployment significantly mold the creation and maintenance of social structures [17]. Green innovation emphasizes the judicious use of resources to reduce ecological harm and resource depletion. Rules represent consistent behaviors adhered to by agents. In the context of green innovation, the formation of frameworks, policies, and legal standards is essential to steer and bolster its sustainable progress. Additionally, the level of technology transfer serves as an indicator of a company's capability for technological innovation, endowing it with a strategic advantage in the marketplace [21].

2.2. *Current research status and indicator interpretation of variables related to green innovation*

Drawing from the structured theoretical framework, each chosen variable is critically examined not just for its historical significance in the field of green innovation but for the unique perspective and contribution our research aims to deliver. Our selection and examination of variables like AC, LF, GSO, RD, FI, EB, TT, and PR are deeply rooted in the foundational theories of enterprise innovation and sustainability but are reconceived through the lens of Giddens' theory of structuration, presenting a novel structural theoretical model that dissects the causal pathways of enterprise green innovation. The value of this study lies in its ability to integrate these diverse variables into a coherent framework, offering strategic insights for policymakers and businesses aiming to enhance their green innovation efforts.

Combining theory of structuration, this paper constructs an explanatory framework for the antecedent and outcome variables of green innovation, as shown in Fig. 1.

2.2.1. *Absorption capacity (AC)*

Absorptive capacity reflects an enterprise's ability to assimilate, integrate, and leverage external knowledge and technologies. This capacity is essential for the effective adoption, utilization, and advancement of green technologies within a firm [22]. stands as a principal measure of absorptive capacity, introducing capital, technology, expertise, and market prospects, thereby enhancing the deployment and advancement of green technologies. Research indicates that FDI considerably boosts innovation in urban environmental protection technologies [23]. Notably, for firms characterized by high technological intensity and substantial added value, FDI exerts a more pronounced influence on their green innovation efforts.

2.2.2. *Location factor (LF)*

In regions endowed with inherent environmental and resource benefits, enterprises exhibit a greater propensity towards engaging in green innovation activities within the realms of environmental protection and energy [24]. Daddi et al.'s empirical investigation into Chinese manufacturing firms demonstrates that the regional industrial agglomeration hosting an enterprise positively influences its green innovative pursuits. Within such clusters, firms enjoy augmented technical support and opportunities for collaboration, thereby nurturing the progression of green innovation [25].

2.2.3. *Green strategy orientation (GSO)*

A green strategic orientation now forms a crucial component of corporate green innovation initiatives. Qu et al. uncovered that an orientation towards green culture fosters improved efficiency in resource utilization while diminishing energy use and emissions among enterprises [26]. Furthermore, Abbas et al. posited that adopting a green cultural mindset enhances a company's consciousness and appreciation of its environmental and social duties, thereby stimulating the embrace of green technologies and production techniques [27].

2.2.4. *R&D investment (RD)*

R&D act as the cornerstone and catalyst for green innovation, providing businesses with technological, product, and service support

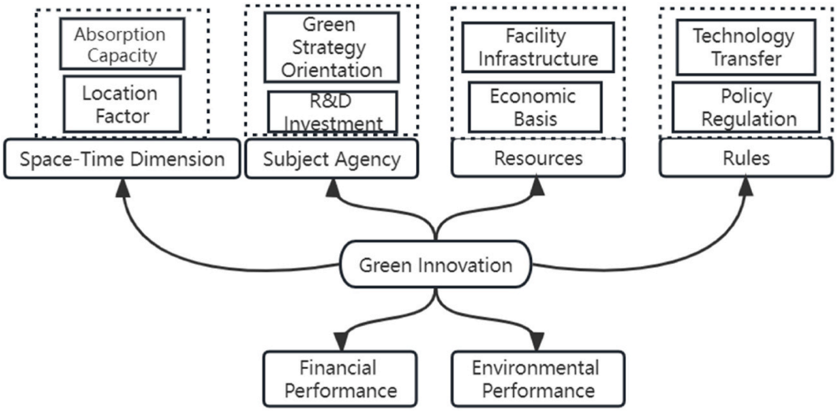

Fig. 1. Explanatory framework of green innovation antecedents and outcome variables.

and confidence. Qamruzzaman et al. established that R&D investment plays a significant role in advancing green innovation within firms [28]. Enhanced R&D funding enables companies to perpetually elevate their technological and product standards, securing a market competitive edge. Additionally, Zhang et al. demonstrated that R&D expenditures can foster innovation in environmental preservation and sustainable corporate growth [29].

2.2.5. Facility infrastructure (FI)

FI represents a fundamental pillar for companies engaged in green innovation, where a solid infrastructure aids in effectively realizing their green innovation objectives. Sun et al. identified that research institutions provide pivotal innovation and technical backing, in addition to market opportunities, to corporations. Such support enhances environmental governance, mitigates adverse ecological effects, and, consequently, fosters environmental innovation, especially within large and multinational corporations [15].

2.2.6. Economic basis (EB)

Purwandani's study indicates that with sufficient financial backing, companies can more adeptly execute environmental and sustainability agendas [14]. However, funding also imposes constraints on corporate green innovation. Firstly, investment hazards exist within the capital market, necessitating that firms account for market fluctuations and investment risks when securing financial support [30]. Secondly, the capital market typically prioritizes short-term gains over long-term sustainability, potentially leading to inadequate funding for green innovation and thus curbing their ecological advancement.

2.2.7. Technology transfer (TT)

Converting research outcomes into tangible solutions can unlock new business prospects and realms of innovation for firms, bolstering their green innovation prowess and market competitiveness [31]. Song et al. elucidated that via technology transfer, companies can refine and elevate existing green technologies and offerings to meet evolving market needs and consumer desires [32]. Such technology transfer aligns corporate green innovation successes with societal and ecological requirements, thereby garnering enhanced societal acknowledgment and backing.

2.2.8. Policy regulation (PR)

Zhang et al.'s investigation reveals that policy measures can foster green innovation through the enforcement of compulsory environmental criteria alongside incentives and deterrence mechanisms, including elevating environmental benchmarks, reducing emission thresholds, and intensifying environmental tax regimes [33]. Concurrently, such regulatory frameworks can escalate corporate environmental expenses and risks, compelling firms to pursue technological innovation and innovation management, thereby stimulating advancements in green innovation [34].

This study aims to delve deeper into these areas, exploring how each factor influences or hinders the process of green innovation, and how these factors interact with each other within the framework of structuration theory. By doing so, it seeks to provide a more comprehensive and nuanced understanding of the dynamics at play, addressing inconsistencies and filling a notable void in current research which often treats these elements in isolation or neglects the interdependencies among them. The significance of this study at this time is multifaceted: environmentally, as corporate entities increasingly become focal points for sustainability efforts; economically, as innovation drives competitive advantage and market success; and socially, as businesses are pressured to assume greater responsibility for environmental stewardship. Building on previous work, this study integrates and extends the literature by offering a structural theoretical model that encapsulates the complex interrelations and mutual influences among the varied elements contributing to green innovation.

3. Research methodology and research process

3.1. Meta-analytical research methods

Meta-analysis, initially rooted in Fisher's concept of "combining p-values" [35], was further refined by Glass who introduced the "combined statistic" [36], enhancing the methodology. This analytical approach synthesizes existing scholarly works to amalgamate numerous independent study outcomes, rectify human statistical errors, and merge quantitative findings for a more holistic and unbiased conclusion.

Echoing scholars like Schmidt [37], the process of meta-analysis typically involves: 1) pinpointing research topics with existing disputes or gaps; 2) gathering and vetting relevant literature; 3) categorizing the data from these sources; 4) conducting data analysis and tests; 5) interpreting the findings.

For data analysis, this study employs the user-friendly and comprehensive CMA software, a staple in the social sciences realm. It offers an array of sophisticated features for data entry, analysis, and presentation.

The model-building process in this study involves the integration of structuration theory with green innovation practices, a methodological approach that has not been extensively explored in existing literature. This novel application aims to uncover the multifaceted dynamics influencing corporate green innovation. The testing approach for our meta-analytical model involves systematic review techniques and statistical analysis to evaluate the strength and direction of relationships between structuration elements and green innovation outcomes. Similar methodologies have been employed in previous studies, such as the work of Mady et al. [38], which investigated environmental innovation practices in manufacturing firms, and Cheng et al. [39], who explored sustainable innovation strategies in technology companies. By referencing these methodologies, our study not only adheres to established research protocols but also extends the application of these models to the domain of green innovation within corporate settings.

3.2. Data collection and processing

3.2.1. Literature search. The focal research theme of this paper is "green innovation." Prior to executing a literature review, the study delineates a tailored search strategy, encompassing databases, timeframes, and key terminologies. To assure the validity and veracity of the outcomes, the paper outlines a methodical approach for the literature inquiry, involving: 1) defining the period from January 2012 to January 2023, conducting searches across various Chinese and English databases such as CNKI, Scopus, and Web of Science, selecting search facets like "title," "subject," "keywords," "full text," employing terms related to "green innovation," alongside "R&D investment," "absorptive capacity," "location factors," "economic foundation," "infrastructure," "green strategic orientation," "achievement transformation," "policy regulation," "economic performance," "environmental performance" within structured frameworks; 2) verifying the inclusion of all relevant literature by examining the references of the gathered documents; 3) reaching out to fellow researchers active in green innovation studies to acquire unpublished papers or data, elucidating the reasons behind the request.

3.2.2. Literature screening. Drawing on the research theme and insights from Song's investigation [40], this paper establishes meticulous literature screening criteria to optimally align the research sample with the objectives of this study: 1) the research should be an empirical examination of the dynamics between the designated variables of this manuscript and green innovation; 2) it must be rooted in quantitative analysis; 3) it should encompass correlation coefficients or analogous measures convertible into correlation coefficients; 4) the document must disclose the sample size.

Guided by these criteria, the initial review identified 13,919 articles related to the research topic. Subsequent filtration excluded unsuitable entries, culminating in 161 pertinent studies. Detailed breakdowns for each variable are tabulated in Table 4, while Fig. 2 illustrates the outcomes of the literature screening process.

3.2.3. Literature code. This study employs Lipsey and Wilson's coding approach to initially categorize the characteristics of literature selected for the meta-analysis [41], including details such as author name, publication year, and sample size. Subsequently, the research item descriptions and effect size statistics are encoded, derived by the coder from the design and conclusion segments of the reviewed articles. The effect size is identified as a correlation coefficient r or a metric translatable into such a coefficient, including t-values, F-values, chi-square values, and regression coefficients.

Utilizing the aforementioned coding strategy, two independent researchers undertook the encoding task. Upon completing the initial coding, discrepancies were collaboratively addressed until consensus was achieved, mitigating subjective biases. After two rounds of deliberation, coder agreement reached 91 %. For unresolved differences, the input from the author and an additional researcher was sought to achieve alignment. Ultimately, from 161 articles, 288 effect sizes were recorded.

3.3. Main steps of a meta-analysis

3.3.1. Effect value conversion. In this research, Fisher's z-value was employed as the effective metric for evaluating the relationship between variables, with the correlation coefficient r serving as the effect size indicator. When the sample literature explicitly reports the correlation coefficient r among variables, Formula (1) is directly applied to transform it into Fisher's z-value. Conversely, if the literature provides only the regression coefficient, t-value, F-value, or chi-square value, these are first converted into the correlation coefficient r using respective calculation formulas, and subsequently transformed into Fisher's z-value. Following this, Formula (2) is utilized to ascertain the standard error of Fisher's z-value. The cumulative effect size is then reverted to the correlation coefficient for inclusion in the research synopsis.

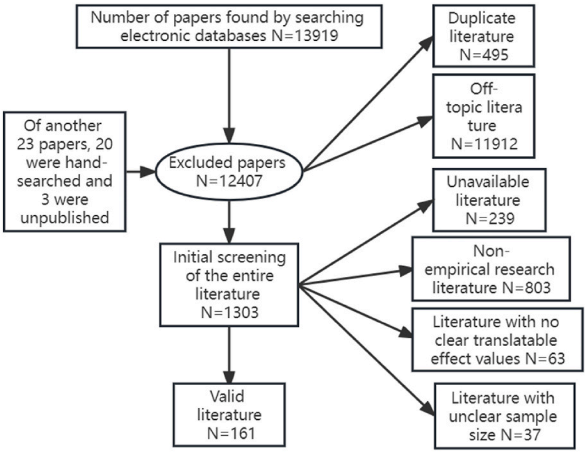

Fig. 2. Literature screening process and results.

$$\text{Fisher}'\text{s Z} = \frac{1}{2}\ln\left(\frac{1+r}{1-r}\right) \tag{1}$$

$$\text{SE} = \frac{1}{\sqrt{N_i - 3}} \tag{2}$$

* In the above equation, r represents the original correlation coefficient, ln is the natural logarithm, SE is the standard error, and Ni is the sample size of the i-th independent study.

3.3.2. Publication bias. Rothstein conducted an analysis of publication bias through diverse methodologies and offered strategies for its mitigation [42]. This research employs two principal techniques from meta-analysis scholarship to evaluate publication bias: the inspection of funnel plots and the application of the "fail-safe N″ statistic.

Per the visual data in Figs. 3–12, the analyzed effect values from the reviewed literature delineate the interrelations between green innovation and assorted variables. The effect sizes related to environmental performance, location factors, R&D investment, facilities infrastructure, economic underpinnings, and outcome transformation manifest symmetrically across the funnel plot's axis, indicating an absence of publication bias in the exploration of these elements with green innovation. Conversely, the effect values pertaining to economic performance, absorptive capacity, green strategic orientation, and policy measures exhibit asymmetrical distributions, hinting at potential publication bias within these specific areas of inquiry.

While a funnel plot serves as an initial tool to detect publication bias visually, it introduces a degree of subjectivity due to its graphical nature. Thus, for enhanced reliability in the analysis, it becomes essential to compute the "fail-safe N″ statistic to gauge publication bias with greater precision. The CMA software employs Formula (3) to determine Rosenthal's fail-safe N, with the analytical outcomes displayed in Table 1. At an alpha level of 0.05, the fail-safe N values for the associations between green innovation and each respective variable exceed their corresponding threshold values, signifying that the meta-analysis findings of this investigation possess solid dependability with no discernible publication bias.

$$N_{fs} = \left(\sum \frac{SE_i}{SE_a}\right)^2 - K \tag{3}$$

In the aforementioned formula, SEi denotes the standard error aligned with the significance level for the i-th independent analysis, SEa signifies the established one-tailed significance level of P, and K symbolizes the quantity of independent studies encompassed in the original scholarly works.

3.3.3. Heterogeneity analysis. In this study, Q-value and I^2-value were selected as indicators to determine the heterogeneity of the sample literature. Q-value represents the sum of standardized effect values squared ($Q = \sum w_i(ES_i - \overline{ES})^2$), which follows a χ^2 (K-1) distribution. When Q > K-1 (Q-value exceeds the critical value of χ^2 (K-1) at the 95 % confidence level), it indicates that the effective values of the sample literature are heterogeneous, and a random-effects model should be used for analysis. In addition, based on the χ^2-test, the I^2 test can indicate the percentage of heterogeneity in the total effect value among the sample literature ($I^2 = 100\% \times (Q - df)/Q$). When $I^2 > 50$ %, it indicates a strong heterogeneity among the sample literature.

Table 2 delineates the outcomes of the heterogeneity examination within this investigation. The Q values derived from this analysis correspond to a P value of 0.000 ($P < 0.05$), substantiating the existence of heterogeneity across the sampled literature incorporated into the meta-analysis. The I^2 values, surpassing 90 %, reveal that the vast majority of observed variance, over 90 %, is attributable to actual disparities in effect sizes, with under 10 % resulting from random discrepancies, highlighting differences in variable measurement and study selection across the collected works. Additionally, the Tau^2 values are uniformly below 0.1, signifying that the

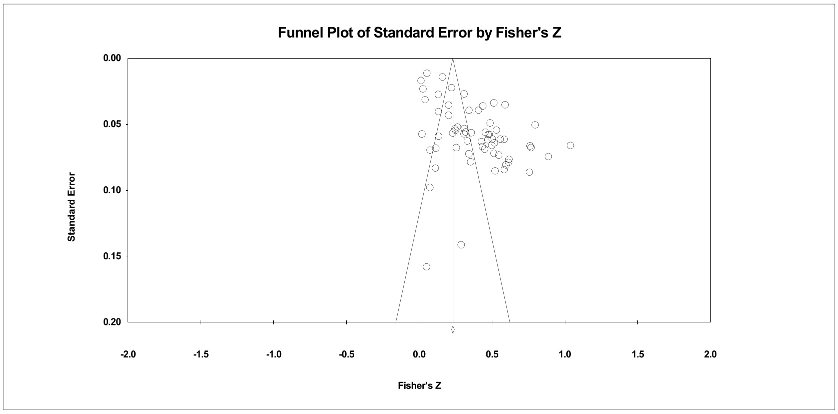

Fig. 3. Green innovation financial performance funnel plot.

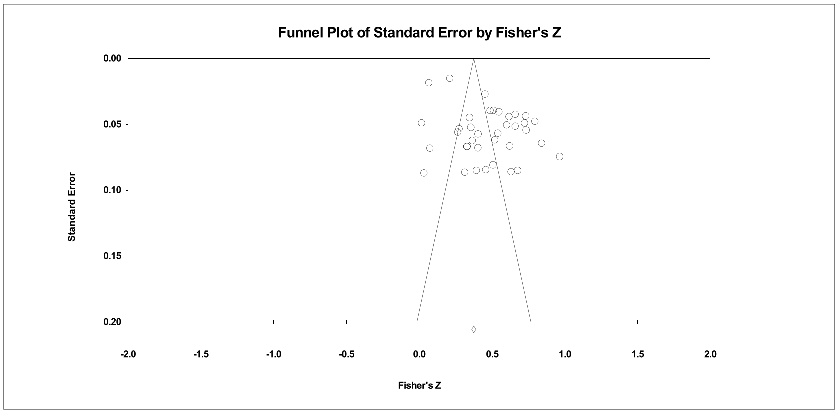

Fig. 4. Green innovation environmental performance funnel plot.

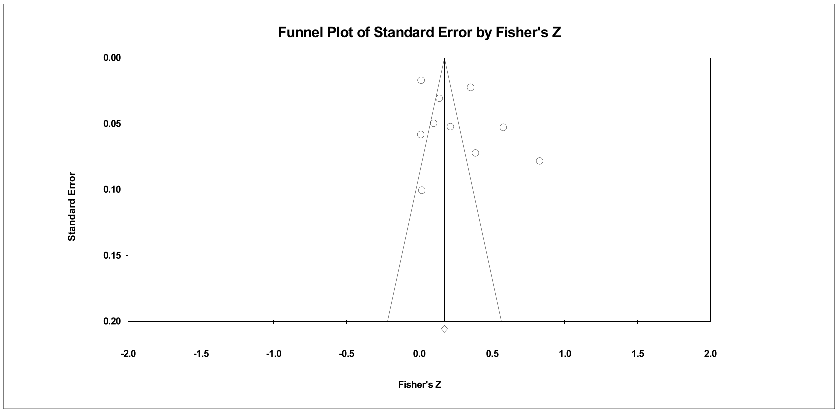

Fig. 5. Location factor funnel plot.

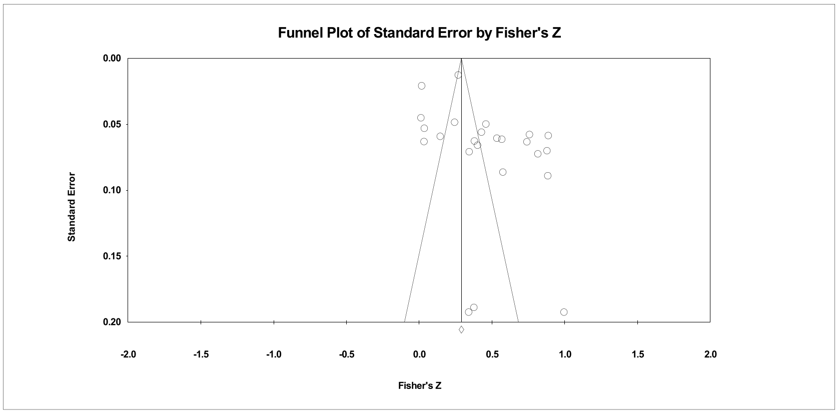

Fig. 6. Absorption capacity funnel plot.

proportion of weight calculation among the studies is under 10 %. Owing to this study's concentration on the principal effect variable model regarding the theory of structuration's role in green innovation and due to space constraints of the article, it temporarily omits considerations of other heterogeneity-induced effect issues. Consequently, informed by the heterogeneity test results, this research opts for a random effects model in its analytical approach.

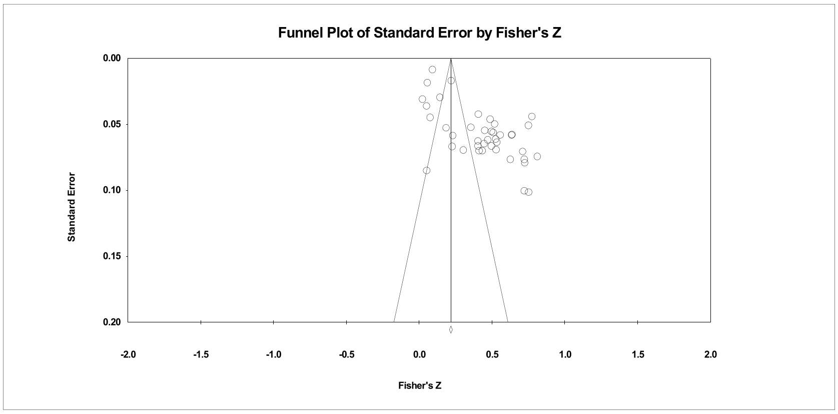

Fig. 7. Green strategy orientation funnel plot.

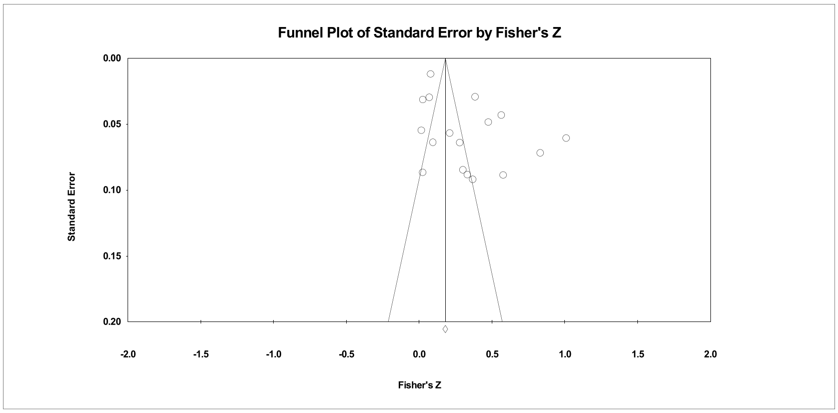

Fig. 8. R&D investment funnel plot.

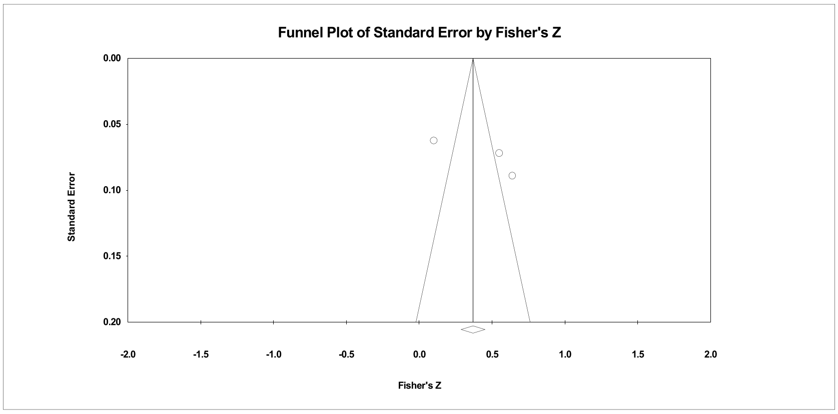

Fig. 9. Facility infrastructure funnel plot.

4. Meta-analysis study results and discussion

4.1. Meta-analysis results of structured independent variables for green innovation

In this research, the Pearson correlation coefficient method was employed, utilizing the r value as the criterion for gauging the correlation intensity between variables. Typically, an r value nearing 1 signifies a strong relationship between two variables, whereas an r value approaching 0 indicates a weaker connection. The specific degrees of correlation denoted by the r values are tabulated in

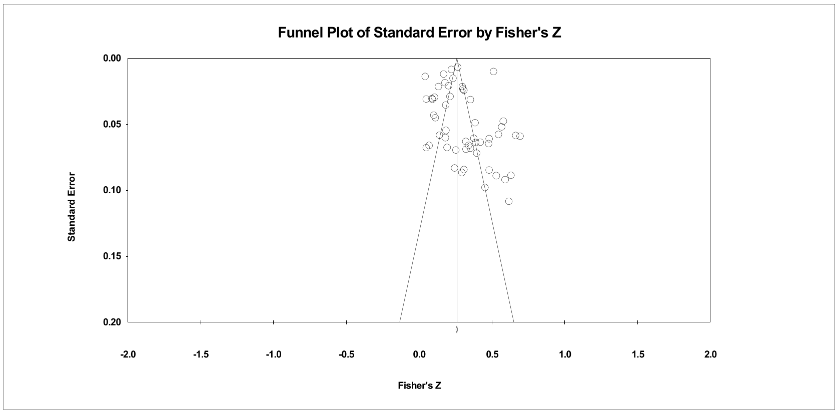

Fig. 10. Economic basis funnel plot.

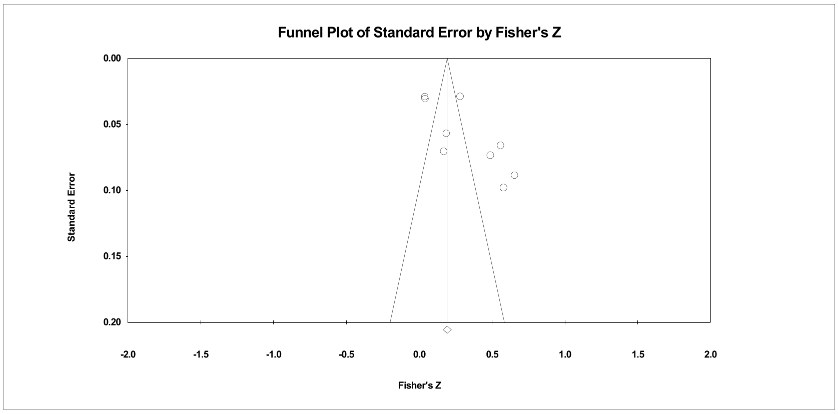

Fig. 11. Technology transfer funnel plot.

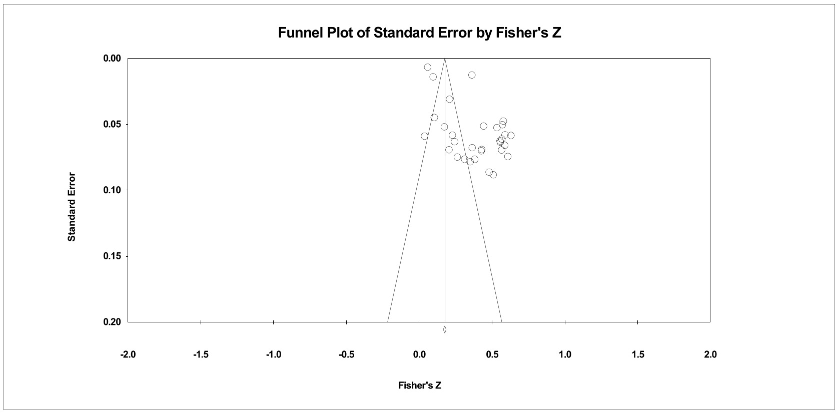

Fig. 12. Policy regulation funnel plot.

Table 3 [43]. Additionally, the significance of the Pearson correlation can be assessed via the P value; a P value less than 0.05 denotes a significant correlation between the variables, while a higher value suggests no significant relationship.

In line with the random effects model, the effect values associated with green innovation, independent, and outcome variables are computed and modified accordingly. The reciprocal of the variance for each research effect size is utilized as weights, enabling the linear weighting of each respective effect value. formula (4) is used for conversion, where the standard error of the comprehensive effect value $\overline{ES_z}$ corresponds to SE_z (calculated using formula 5).

Table 1
Fail-safe N.

Relation	5K + 10	Fail-safe N	Z-value	p
AC-GI	130	7697	35.154	0.000
LF-GI	60	771	17.319	0.000
GSO-GI	215	5352	48.777	0.000
RD-GI	95	2685	24.709	0.000
FI-GI	25	68	9.503	0.000
EB-GI	275	9722	60.064	0.000
TT-GI	55	559	15.557	0.000
PR-GI	165	3647	41.170	0.000
GI-FP	325	8627	54.487	0.000
GI-EP	195	8773	54.691	0.000

Table 2
Heterogeneity test.

Relations	K	Heterogeneity				Tau-squared	
		Q	df(Q)	P	I2	Tau2	Std.E
AC-GI	24	726.154	23	0.000	96.83	0.067	0.040
LF-GI	10	303.797	9	0.000	97.037	0.047	0.034
GSO-GI	41	1372.078	40	0.000	97.085	0.051	0.027
RD-GI	17	587.559	16	0.000	97.277	0.060	0.038
FI-GI	3	34.042	2	0.000	94.125	0.087	0.094
EB-GI	53	1515.981	52	0.000	96.570	0.018	0.008
TT-GI	9	151.580	8	0.000	94.722	0.039	0.027
PR-GI	31	1156.595	30	0.000	97.406	0.041	0.029
GI-FP	63	1770.433	62	0.000	96.498	0.046	0.016
GI-EP	37	1069.543	36	0.000	96.634	0.058	0.023

Table 3
Correlation coefficient.

Correlation coefficient	Relevance
$r = 0$	Irrelevant
$0 < r \leq 0.3$	Weak correlation
$0.3 < r \leq 0.5$	Low correlation
$0.5 < r \leq 0.8$	Significant correlation
$0.8 < r \leq 1$	Highly correlation
$r = 1$	Completely correlation

Table 4
Results of effect size test.

Variables			K	N	Effect size and 95 % confidence interval			Two-tailed test	
					Point estimate	Lower limits	Upper limits	Z-value	P-value
Independent Variables of green innovation	Space-Time	AC-GI	24	11975	0.456	0.564	0.347	8.226	<0.001
	Dimension	LF-GI	10	6493	0.263	0.402	0.124	3.713	<0.001
	Subject Agency	RD-GI	17	12509	0.319	0.422	0.207	5.370	<0.001
		GSO-GI	41	15924	0.434	0.506	0.362	11.849	<0.001
	Resources	EB-GI	53	36978	0.305	0.345	0.266	15.177	<0.001
		FI-GI	3	585	0.427	0.771	0.083	2.433	0.015
	Rules	TT-GI	9	4626	0.322	0.457	0.186	4.655	<0.001
		PR-GI	31	18523	0.386	0.460	0.312	10.172	<0.001
Outcome variables of green innovation	GI-FP		63	34401	0.382	0.437	0.327	13.636	<0.001
	GI-EP		37	17147	0.473	0.553	0.393	11.606	<0.001

Note: K is the number of independent sample documents, and N is the total sample size used in all K studies.

$$\overline{ES_z} = \sum w_i \frac{ES_{zi}}{\sum w_i} \tag{4}$$

$$w_i = N_i - 3$$

$$SE_z = \frac{1}{\sum \sqrt{N_i - 3}} \tag{5}$$

As delineated in Table 4, there exists a noteworthy positive correlation between absorptive capacity and green innovation across spatiotemporal dimensions, showcased by an effect value of 0.456 and a 95 % confidence interval ranging from a lower limit of 0.247 to an upper limit of 0.564. This interval notably excludes 0, and with a Z-value of 8.226 ($P < 0.001$), the statistical significance of this result is affirmed. Additionally, there is a positive link between location factors and green innovation, reflected by an effect value of 0.263 ($P < 0.001$). This suggests a moderate validation of the theoretical interconnection between location factors and green innovation. However, the significance of location factors may vary, requiring case-by-case analysis. In the context of the evolving digital and information technology landscape, certain green innovations transcend traditional geographic constraints, affirming the need for nuanced interpretation of location factors. Despite the substantial sample size associated with location factors, the robustness of these findings is tempered by the limited number of effect values from the sampled literature, indicating a direction for future investigative pursuits.

Within the subject energy dimension, a positive link is established between R&D investment and green innovation, denoted by an effect value of 0.319 ($P < 0.001$). Furthermore, green strategic orientation is significantly positively associated with green innovation, reflected by an effect value of 0.434 ($P < 0.001$).

In the resource dimension, there is a notable positive relationship between economic foundation and green innovation, indicated by an effect value of 0.305 ($P < 0.001$). Similarly, a significant positive correlation exists between facility foundation and green innovation, with an effect value of 0.427 ($P = 0.015$). While these findings validate the theoretical link between facility foundation and green innovation to a certain degree, the small sample size and limited robustness call for further inquiry.

In the rules dimension, a significant positive correlation is identified between technology transfer and green innovation, evidenced by an effect value of 0.322 ($P < 0.001$). Additionally, a marked positive relationship is observed between policy regulation and green innovation, with an effect value of 0.386 ($P < 0.001$).

4.2. Meta-analysis results of structured outcome variables for green innovation

The study findings reveal a significant positive association between green innovation and economic performance, indicated by an effect size of 0.382 ($P < 0.001$). Nonetheless, the influence of green innovation on a firm's economic outcomes is not straightforward. Interactions among numerous factors within the social system can yield unpredictable consequences. For instance, adopting specific green technologies might necessitate substantial investment and research from an enterprise, thus elevating their operational costs and associated risks.

The research findings indicate a substantial positive link between green innovation and environmental performance, demonstrated by an effect value of 0.473 ($P < 0.001$). Green innovation plays a pivotal role in diminishing the environmental risks faced by enterprises. By integrating green technologies and machinery, businesses are able to lower their pollutant emissions and waste production, consequently mitigating environmental hazards. Furthermore, the adoption of renewable energy, along with the recycling and repurposing of waste materials, facilitates efficient resource utilization and ecological sustainability, thereby lessening the enterprises' environmental footprint.

5. Meta-analysis results and discussion on large-scale enterprises and small and medium-sized enterprises (SMEs)

5.1. Large-scale enterprise meta-analysis results and discussion

To elucidate the relationship between precursor and resultant variables of green innovation across enterprises of varying sizes, this study delves into the distinctions between large-scale entities and SMEs, as delineated in the sampled literature. Owing to the scant classifications based on location factors and facility configuration, these were omitted from this segment of the analysis. As illustrated in Table 5, the meta-analysis outcomes for large-scale corporations exhibit high dependability with negligible publication bias. The Q values for absorptive capacity, R&D investment, green strategic orientation, economic underpinnings, outcome transformation, and economic and environmental performance all yield a P value of 0.000 ($P < 0.05$), with I^2 values registering at 94.909 %, 85.246 %, 93.098 %, 91.958 %, 96.938 %, 73.130 %, and 94.668 %, respectively, signifying notable heterogeneity within the examined literature. Accordingly, a random-effects model was adopted for analysis. In contrast, the heterogeneity in policy regulation appeared insubstantial, thus a fixed-effects model was employed.

Significant positive correlations exist between absorptive capacity, R&D investment, policy regulation, and the green innovation of large-scale enterprises, manifesting effect sizes of 0.209 ($p < 0.05$), 0.261 ($p < 0.01$), and 0.169 ($p < 0.05$), respectively. Notably, a strong positive association is observed between green strategic orientation, economic underpinnings, technology transfer, and green innovation, with effect sizes recorded at 0.559 ($P < 0.01$), 0.376 ($P < 0.01$), and 0.429 ($P < 0.01$), respectively. Additionally, there exists a positive relationship between green innovation and both economic and environmental performance, evidenced by effect sizes of 0.205 ($P < 0.01$) and 0.232 ($P < 0.05$), respectively.

Table 5
Test results of publication bias and heterogeneity for large-scale enterprises.

Relation	K	N	Fail-safe N	Heterogeneity			Tau-squared		Effect size and 95 % confidence interval			Two-tailed test	
				Q	P	I2	Tau2	Std.E	Point estimate	Lower limits	Upper limits	Z-value	P-value
AC-GI	4	7091	210	58.922	0.000	94.909	0.033	0.034	0.209	0.378	0.027	2.245	0.025
RD-GI	8	3504	422	47.444	0.000	85.246	0.020	0.017	0.261	0.364	0.152	4.600	0.000
GSO-GI	7	1497	924	86.937	0.000	93.098	0.065	0.042	0.559	0.679	0.409	6.292	0.000
EB-GI	20	15361	6574	236.254	0.000	91.958	0.017	0.010	0.376	0.430	0.320	12.121	0.000
TT-GI	4	1614	124	97.985	0.000	96.938	0.139	0.140	0.429	0.682	0.085	2.404	0.016
PR-GI	6	2576	94	10.424	0.064	52.032	0.003	0.004	0.169	0.224	0.103	8.545	0.000
GI-FP	12	4293	424	40.937	0.000	73.130	0.008	0.006	0.205	0.270	0.141	6.209	0.000
GI-EP	5	6097	322	75.014	0.000	94.668	0.025	0.023	0.232	0.375	0.088	3.166	0.002

5.2. Small and medium-scale enterprise meta-analysis results and discussion

As indicated in Table 6, the meta-analysis outcomes for SMEs demonstrate robust reliability with no evident publication bias. The Q values pertaining to absorptive capacity, R&D investment, green strategic orientation, economic underpinnings, policy regulation, and both economic and environmental performance all register $P < 0.05$, with respective I^2 values of 82.249 %, 9.609 %, 82.415 %, 85.159 %, 64.497 %, 93.138 %, and 88.519 %. This reflects significant heterogeneity within the included sample literature, thus a random effects model has been adopted for the analysis. Conversely, due to the non-significant heterogeneity results of outcome transformation, a fixed effects model was employed for its examination.

In SME enterprises, there exists a pronounced positive correlation between absorptive capacity, green strategic orientation, and policy regulation with green innovation, indicated by effect sizes of 0.467 ($P < 0.01$), 0.412 ($P < 0.01$), and 0.514 ($P < 0.01$), respectively. Additionally, positive associations are observed between R&D investment, economic underpinnings, and technology transfer with green innovation, denoted by effect sizes of 0.270 ($P > 0.1$), 0.220 ($P < 0.05$), and 0.252 ($P < 0.01$). Moreover, there is a significant positive correlation between green innovation and both economic and environmental performance, with effect values of 0.481 ($P < 0.01$) and 0.609 ($P < 0.01$), respectively.

5.3. Comparative analysis of large-scale enterprises and small and medium-scale enterprises

This article delves deeper into structural outcomes based on enterprise size, with findings delineated in Table 7. Notably, green strategic orientation and outcome transformation exhibit significant positive correlations across both large and SME sectors. While absorptive capacity and green innovation show a modest link in larger firms, a robust correlation is apparent within SMEs. Given their distinct positions within the social fabric, SMEs, characterized by their lesser scale and enhanced adaptability, are more adept at responding to environmental shifts, thereby better positioned to assimilate and implement novel knowledge, skills, and technologies [44]. Conversely, the intricate organizational frameworks and managerial hierarchies of larger corporations tend to slow decision-making processes, hindering their capacity to integrate fresh insights and expertise.

R&D investment exhibits a pronounced correlation in large-scale enterprises but a more subdued one in SMEs. Due to their considerable size and resource privileges, larger enterprises can afford substantial R&D investments and engage in intricate and riskier green innovation endeavors [45]. Conversely, SMEs frequently grapple with resource scarcity and financial constraints, precluding them from pursuing complex and hazardous research initiatives, thus curtailing their capacity for green technological innovation.

Regarding economic underpinnings, a robust link is evident between large-scale firms and their economic foundations, whereas a tenuous connection exists between SMEs and their economic structures. Large corporations, by virtue of their size and resource access, are better positioned to secure substantial capital and external funding [46]. Additionally, these entities typically maintain more stable fiscal standings and credibility, facilitating easier access to financial backing from external sources [47]. On the other hand, SMEs often encounter funding obstacles and heightened financing expenses, restricting their green innovation investment capabilities.

Table 6
Test results of publication bias and heterogeneity for small and medium-scale enterprises.

Relation	K	N	Fail-safe N	Heterogeneity			Tau-squared		Effect size and 95 % confidence interval			Two-tailed test	
				Q	P	I2	Tau2	Std.E	Point estimate	Lower limits	Upper limits	Z-value	P-value
AC-GI	6	1676	633	28.167	0.000	82.249	0.017	0.013	0.467	0.552	0.372	8.596	0.000
RD-GI	3	884	61	83.657	0.000	97.609	0.150	0.156	0.270	0.332	0.206	1.549	0.121
GSO-GI	9	2569	1104	45.493	0.000	82.415	0.017	0.010	0.412	0.486	0.331	9.183	0.000
EB-GI	3	763	27	13.476	0.001	85.159	0.023	0.028	0.220	0.390	0.036	2.331	0.020
TT-GI	3	1719	60	3.763	0.152	46.850	0.002	0.005	0.252	0.299	0.204	10.414	0.000
PR-GI	4	1034	335	8.450	0.038	64.497	0.007	0.009	0.514	0.587	0.433	10.685	0.000
GI-FP	9	2153	1118	116.582	0.000	93.138	0.058	0.032	0.481	0.644	0.318	5.782	0.000
GI-EP	7	1815	1195	52.261	0.000	88.519	0.031	0.021	0.609	0.748	0.470	8.608	0.000

Table 7
Summary of study results.

Variables			Enterprise scale	Correlation coefficient	Significance	Significance intensity
Independent variables of green innovation	Space-Time Dimension	AC-GI	Large Scale	0.209	Significant	Weak
			Small and Medium-scale	0.467	Significant	Strong
	Subject Agency	RD-GI	Large Scale	0.261	Significant	Strong
			Small and Medium-scale	0.270	Not significant	Weak
		GSO-GI	Large Scale	0.559	Significant	Strong
			Small and Medium-scale	0.412	Significant	Strong
	Resources	EB-GI	Large Scale	0.376	Significant	Strong
			Small and Medium-scale	0.220	Significant	Weak
	Rules	TT-GI	Large Scale	0.429	Significant	Strong
			Small and Medium-scale	0.252	Significant	Strong
		PR-GI	Large Scale	0.169	Significant	Weak
			Small and Medium-scale	0.514	Significant	Strong
Outcome variables of green innovation	GI-FP		Large Scale	0.205	Significant	Weak
			Small and Medium-scale	0.481	Significant	Strong
	GI-EP		Large Scale	0.232	Significant	Weak
			Small and Medium-scale	0.609	Significant	Strong

The association between policy regulation and large-scale enterprises is modest, whereas it is pronounced for SMEs. SMEs typically encounter heightened risks in green innovation, where policy regulation can offer essential safeguards and backing, aiding them in navigating market competition and uncertainties. In contrast, large-scale enterprises, with their abundant resources and market dominance, possess a greater capacity to independently manage market challenges and competitiveness [48]. Though policy regulation exerts a lesser influence on larger firms, it still furnishes crucial guidelines and standards for their developmental trajectory and social responsibilities.

The economic and environmental performance associated with green innovation exhibits a weak correlation in large-scale enterprises and a pronounced one in SMEs. The compact nature of SMEs allows them more agility in modifying production processes and product designs to diminish environmental pollution and resource waste [49]. Additionally, they can decrease production expenses and enhance efficiency by embracing new technologies and methodologies like energy-efficient equipment, renewable resources, and sustainable materials. In contrast, large corporations must navigate their extensive supply and value chains, alongside intricate production workflows and organizational frameworks, complicating their green innovation efforts.

6. Discussion

Firstly, this study contributes to the green innovation literature by offering a structured interpretation of how different factors influence corporate sustainability efforts. Unlike previous studies, which may have explored these elements in isolation, our research integrates them within a comprehensive framework, guided by structuration theory. Additionally, the examination of green innovation's impact on economic and environmental outcomes corroborates its congruence with structuration theory, underscoring green innovation as a pivotal strategy for enterprises pursuing economic sustainability. This stands in contrast to Yi's assertion that green product innovation's economic gains might be compromised by widespread imitation [50]. It also aligns with the perspective of scholars advocating that green innovation can environmentally reallocate resources, fostering sustainable growth in corporate economic performance [51]. This not only contradicts earlier skepticism but also illustrates the nuanced ways in which green innovation can be harnessed to balance economic and environmental goals. From a social perspective, this study contributes to a deeper understanding of how enterprises can be instrumental in advancing sustainable development goals. By demonstrating the positive correlation between green innovation and corporate sustainability efforts, this research supports the notion that businesses play a pivotal role in addressing global environmental challenges. Furthermore, this investigation not only substantiates the theoretical aspects of structuration theory, including temporal, subjective, and structural dimensions but also merges them with quantifiable variable models, positing structuration theory as a foundational framework for elucidating variables influencing green innovation.

Secondly, this paper delineates how green innovation's impact fluctuates with enterprise size. Segmenting according to enterprise size, it substantiates significant variances in the dynamics between green innovation and its various precursors and outcomes among differently sized enterprises. This aligns with scholarly opinions positing that large corporations wield stronger resource capabilities and market presence in green innovation, fostering eco-friendly products and services while contending with challenges like inertia [46,47]. Conversely, smaller enterprises exhibit greater ingenuity and adaptability in green innovation [44,49], swiftly adjusting to market and environmental shifts, yet are hampered by financial and technological constraints. This segmentation reveals that while larger firms may have more resources, they also face greater inertia, contrasting with smaller firms that exhibit flexibility but encounter resource limitations.

Significantly, our study diverges from conventional analyses by examining how enterprise size affects green innovation, providing a nuanced understanding that challenges one-size-fits-all strategies. This is particularly pertinent in light of the growing importance of sustainable practices across different scales of businesses, as outlined by scholars like Leonidou et al. [52]. By correlating structural theory's dimensions with green innovation's practical impacts, we not only provide empirical evidence but also propose a foundational framework that enhances the understanding of the factors driving green innovation. Our findings offer significant theoretical contributions and practical implications for advancing sustainable green innovation strategies in corporations of varying sizes. These strategies are critical in aligning business practices with sustainable development goals, contributing to a holistic understanding of green innovation.

7. Conclusion

Drawing on 161 independent empirical studies conducted both domestically and internationally from 2012 to 2023, this research employs quantitative meta-analysis to reevaluate the connection between the theory of structuration and corporate green innovation, alongside their respective dimensions. The study probes the factors affecting variable relationships across distinct dimensions and amalgamates existing divergent research findings to establish a uniform theoretical consensus. Findings indicate that each aspect of the theory of structuration positively influences corporate green innovation, offering fresh substantiation for the alignment between the theory of structuration and the green innovation trajectory.

7.1. Recommendations for management

For large-scale enterprises, enhancing capital utilization efficiency can bolster green innovation initiatives. Firstly, firms should reform their internal structures and broaden their financing avenues. Securing additional funds through bank loans, equity financing, and other methods can substantially underpin the company's green innovation endeavors. Secondly, amplifying risk management via the establishment of mechanisms, the standardization of corporate conduct, and the minimization of operational hazards can fortify the safety and stability of funds, thereby offering stronger financial backing for green innovation projects. Lastly, leveraging big data to grasp market trends, uncover concealed insights, and foster collaborations with external entities can draw augmented support in human, financial, and physical resources. Additionally, governmental bodies should extend financial assistance and enhance research and development allocations to inspire corporate participation in green innovation activities.

For SMEs, establishing a robust knowledge management system is crucial. This includes the gathering, analysis, and amalgamation of external information. Firms can accrue green innovation-related data through market research, interactions with suppliers and clients, and participation in sectoral summits, incorporating this intelligence into their knowledge repositories. Additionally, the government should intensify policy regulation: instituting stringent environmental protection legislations and norms that compel businesses to diminish pollution and resource use in production processes, while fostering the adoption of sustainable and low-carbon solutions, thus advancing green innovation. Moreover, the government could offer tax breaks and financial inducements to stimulate green innovation and technological advancements, furthering enterprises' ecological transition and creating pertinent credit and financing frameworks to back these initiatives financially. Lastly, enhancing the monitoring and enforcement of environmental regulations ensures that firms adhere to eco-friendly practices and standards, safeguarding natural resources and deterring nefarious corporate conduct.

Moreover, by contextualizing our findings within the global debate on sustainable development and economic growth. It elucidates the diverse pathways through which companies of various sizes can pursue green innovation, highlighting the importance of structural alignment, resource mobilization, and policy support. In conclusion, our study enriches the existing body of knowledge by bridging theoretical concepts with practical applications, offering a holistic view of the mechanisms driving green innovation in the corporate world.

7.2. Research limitations

This study encounters certain limitations that should be acknowledged. Firstly, the diversity in methodological approaches among the analyzed empirical studies introduces variability, potentially impacting the consistency and comparability of our findings. Secondly, due to the study's focused scope and constraints on length, we did not explore mediation and moderation effects in depth, nor did we differentiate among types of green innovation, treating it instead as a unified concept. Furthermore, while our analysis provides a structured interpretation of green innovation within corporations, it does not specifically address the increasingly critical role of digital technology in enhancing industrial structures and processes. The burgeoning field of digital green innovation, especially within integrated green building supply chains, represents a pivotal area for future research. As highlighted by recent studies, understanding the interaction mechanisms and dynamic evolution of digital technologies within green innovation practices is essential for advancing sustainable industrial transformation [53,54].

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Data availability statement

The data that support the findings of this study are available from the corresponding author.

PRISMA statement

Regarding reporting biases (Reporting biases 21): Our research methodology was designed to minimize the risk of potential reporting biases by ensuring a comprehensive and exhaustive literature search along with strict study selection criteria.

Regarding the certainty of evidence (Certainty of evidence 22): Given the scope of this review and the specific nature of the studies involved, we focused on providing clear descriptions of research findings and synthesis analysis without sufficient information to grade the certainty of the evidence.

Regarding registration and protocol (Registration and protocol 24a, 24b, 24c): This review was not pre-registered because, at the time we initiated this work, pre-registration was not widely required by relevant registries for systematic reviews, nor did we prepare a formal protocol document. Additionally, the specific direction and design of the research were already very clear at the start of the study, so there was no instance of protocol amendment.

CRediT authorship contribution statement

Fanbo Li: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hongfeng Zhang:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Linlu Weng:** Writing – review & editing, Resources. **Haoqun Yan:** Writing – review & editing, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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