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Can Technological, Organisational and Environmental Factors Reduce Costs Through Green Innovation in the Construction Industry? Comparison of State-Owned and Private Enterprises

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Abstract

Green innovation (GI) plays a pivotal role in advancing sustainable transformation. To implement the concept of green development, China is vigorously advancing green innovation adoption (GIA). Although prior research has largely focused on the manufacturing sector, little is known about how ownership structures shape GIA in the construction industry, nor about its impact on cost. To address this gap, this study, grounded in the Technology–Organisation–Environment (TOE) framework, investigates the extent to which technological, organisational, and environmental factors influence the GIA in the construction sector and how GIA contributes to cost reduction, as well as how these effects differ between state-owned and private firms. Data were collected from 277 construction enterprises, and analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). Our findings show that GIA significantly reduces costs in both state-owned enterprises (SOEs) and private firms, while market pressure exerts no obvious influence on GIA. Notably, organisational support is found to negatively affect green process innovation in SOEs, suggesting that such initiatives may be more symbolic than substantive. This study could serve as a reference for businesses and governments, and contribute to China's new development philosophy of “innovative, coordinated, green, open, and shared.”

Keywords: green innovation adoption; cost reduction; construction industry; TOE framework; ownership



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1. Introduction

Green innovation (GI) is crucial for improving energy efficiency and fostering a green economy, and plays an increasingly important role in sustainable development [1]. Enterprises worldwide have begun to explore new development models represented by GI strategies that promote win-win outcomes for both the economy and the environment [1]. Among them, China is particularly noteworthy: as the largest contributor to energy consumption and carbon emissions, its construction industry accounts for a substantial share of global energy use and emissions [2]. However, the construction sector has not yet achieved a substantive green transition, and its carbon emissions are expected to rise further, intensifying the challenge of global warming. As the world's largest developing economy, if the construction sector is to reach its carbon peak by 2030, China faces mounting pressure to reduce emissions from its construction industry [2]. To address these challenges, the Chinese government has actively promoted green buildings nationwide, fostering the

industry's transition toward low-carbon practices and GI. From design and construction to operation, green buildings incorporate sustainability throughout their life cycle. This not only significantly lowers energy consumption and environmental impacts, but it also offers benefits like lower maintenance and operating costs and improves productivity and health [2,3]. So GI constitutes a vital pathway for the construction industry to meet emission reduction targets and accelerate the development of green buildings.

Given that the benefits of GI are not always captured by enterprises, limited interest has been shown in their green R&D activities. The existing literature indicates that a firm's decision to pursue GI is influenced by its internal cost–benefit analysis [4]. However, not all enterprises, particularly state-owned enterprises (SOEs), engage in GI solely for maximising profits [1]. In developing nations like China, state ownership serves as a primary route for governments to engage in economic activity. The Chinese central and local governments control a vast array of resources and access, and their intervention through market regulation is frequently perceived as a 'grabbing hand' [5]. In contrast to private enterprises, SOEs benefit from favourable protection, resources and policy priorities, but they also face more stringent governmental mandates and social responsibilities [6,7]. Consequently, state ownership significantly influences a company's strategic choices [8]. While SOEs serve as instruments of national policy to achieve sustainable macroeconomic growth and pursue government-set development goals, previous studies have overlooked state ownership as a potential influencer of green innovation adoption (GIA), a key institutional factor in emerging economies [8]. The factors influencing GIA and its performance may vary among construction companies with different ownership structures. Khan et al. (2025) noted that ownership structure shapes how market, enterprise, and policy uncertainties affect GI in manufacturing firms, with SOEs experiencing a weaker negative impact from these uncertainties [9]. Wang et al. (2022) highlight that policy incentives exert heterogeneous effects across ownership structures in the physical industry: while environmental incentives boost GI in SOEs, they often inhibit it in non-SOEs [10]. Current research on the determinants of GI has largely focused on the manufacturing sector. However, Korean studies have shown that the construction industry exhibits unique characteristics. Although its products are designed for long duration, due to its labour-centred construction methods, low-tech image, and low productivity, it is generally considered to be slow to adapt to new technologies [11]. In addition, GIA in the construction industry requires large investments, has a long payback period, and is highly dependent on policies [12]. This highlights the need to study GIA in the construction industry. Moreover, there is a gap in understanding how ownership structures matter among the contextual factors on GI and the impacts of GI on cost.

The TOE framework provides a perspective for analysing GIA from the perspectives of technological, organisational, and environmental factors. Its flexibility and adaptability across diverse settings make it highly relevant for contemporary research [13]. The framework is especially well-suited to the construction industry, where technological factors and policy interventions shape the GIA. Relative advantage, compatibility, complexity, trialability, and observability are five technology attributes derived from the TOE framework in the technological context that influence innovation adoption [14]. Trialability and observability primarily apply to explaining whether a company decides to adopt an innovative technology. Since the research subjects are enterprises that have already implemented GI, they are not applicable to this study. Due to the availability of simple management tools, high accessibility, and advanced automation, technological complexity was not shown to be a significant factor in influencing innovation adoption [15]. Therefore, relative advantage and technology compatibility are adopted in this study. In terms of organisational factors, the Natural Resource-Based View (NRBV) believes that an organisation's successful environmental behaviour depends on its key resources and capabilities [16]. GI is often

hindered by high costs, knowledge, market barriers, and associated uncertainties. Existing studies primarily examine the influence of organisational factors on GIA through variables such as firm size and specific available resources [17,18], while evidence on the roles of ECSR, innovation capability, and organisational support remains limited. ECSR plays a critical role in encouraging firms to assume responsibility toward internal and external stakeholders [19,20]. Innovation capability and organisational support are essential for GIA, as companies need foundational knowledge, specialised skills and unique resources to manage organisational changes associated with GI [13,21]. As for environmental factors, according to institutional theory, the external institutional environment constrains operational scope and shapes the strategic responses of the organisation [22]. Policy orientation and market pressure are two key mechanisms influencing institutional isomorphism [22]. In addition, in the Chinese context, environmental compliance is a crucial factor for companies to undertake GI [12]. As a normative pressure, market pressure has been proven to be the critical driving force behind GI in Pakistan and Vietnam [23,24]. However, in contrast, prior research has also produced opposite findings regarding the effects of market pressure [16,25] and policy orientation [26] on GIA. Thus, in the dimension of environmental factors, this study further examines the effect of these two factors (policy orientation and market pressure) on GIA to provide further empirical evidence.

Additionally, prior research has not yielded consistent conclusions on whether GIA can reduce enterprise costs. Some studies indicate that GIA can effectively lower costs by improving energy efficiency and reducing waste [27,28]. Conversely, other researchers argue that investments in GIA may not only fail to offset compliance costs but could also exacerbate the financial burdens [29,30].

In this regard, this study aims to make the following contributions to China's new development philosophy, which emphasises innovation, coordination, green development, openness and sharing. First, it examines whether technological, organisational and environmental factors effectively impact GIA and how these effects differ between state-owned and private construction firms. Second, it examines whether GI effectively reduces enterprise costs and how these effects differ between state-owned and private construction firms. Addressing these questions is crucial for understanding the heterogeneous incentives and constraints faced by enterprises under different ownership structures. This study fills a gap in the literature on GIA in China's construction enterprises and further identifies the distinct factors influencing GI in construction enterprises under different ownership structures, and examines how these factors shape the cost reduction. This study can provide a reference for GIA and government implementation of green strategic behaviours.

The paper is organised into seven parts. A review of the theoretical basis and existing research is presented in Section 2. Section 3 develops a theory-based analytical framework with hypotheses derived from the literature review. Section 4 outlines the study's methodology, and Section 5 analyses the results. Section 6 provides a discussion of the findings, and Section 7 concludes the paper.

2. Literature Review

2.1. TOE Framework

The TOE framework, originally proposed by Tornatzky and Fleischer in 1990 [31], extends the diffusion of innovation (DOI) theory by incorporating an environmental dimension, suggesting that innovations become more complex as business environments become more unpredictable. This theory provides an organisational framework that clarifies how innovation practices are affected by various contexts. The framework explores new technology uptake from three perspectives: technology, organisation, and environment, all of which influence GI practices [31]. This concept was appropriate for understanding technol-

ogy acceptance and distribution, and has been extensively utilised in studies pertinent to technology adoption [18,32,33]. The technological dimension pertains to the applicability of adopting new technologies and the trade-off between benefits and challenges [17]. Organisations should also consider their unique characteristics and all available resources, such as scale, management structure, and organisational culture [17,32], as well as human resources [32], collectively referred to as “organisational factors.” Environmental dimensions within the TOE model encompass external elements, such as government regulations, industry trends, and the existing technological infrastructure of related sectors [17]. The three aspects co-influence the adoption of GI.

2.2. Green Innovation Adoption

GIA involves innovative products or processes development and enhancement aimed at ecological improvement through reduced environmental risks, lower pollution levels, and minimised resources and energy use [34,35]. Based on its environmental impacts, GIA can be divided into green process innovation and green product innovation [35]. Green process innovation is a preventive environmental management strategy focused on improving overall operations, including production and management, to achieve more efficient resource and energy use, thereby reducing total emissions and emission intensity at the end of production [35]. Green product innovation is a relatively advanced model that controls pollutant emissions at the source by designing and developing more environmentally friendly products that integrate functional and green attributes, thereby reducing environmental impacts across the product life cycle [35]. The construction industry faces profound challenges in reducing emissions. In practice, construction companies of the United States achieve green building certification by reducing carbon emissions, lowering energy and water consumption, and recycling construction waste [3]. The Chinese government has been vigorously promoting green buildings across various cities. By embedding sustainability principles into design, construction, and operation, green buildings aim to effectively reduce energy consumption and mitigate environmental pollution throughout their entire life cycle [2]. Although many countries have introduced a range of policies to encourage designers, developers, and contractors to embrace green buildings, these measures remain insufficient to ensure their widespread adoption [36].

2.3. Contextual Factors of Green Innovation Adoption

GIA is frequently viewed as a means of achieving environmental targets in a cost-effective manner. However, GIA and its performance are affected by a range of contextual factors [13]. From a technological perspective, relative advantage and technology compatibility are the key factors influencing innovation practices. Relative advantage refers to the benefits an innovation offers compared to the technology it replaces [14]. The salience of these advantages depends not only on the inherent attributes of the innovation but also on the characteristics of potential adopters. Relative advantages, including economic efficiency, performance improvement, convenience, image enhancement, and social prestige, increase the likelihood of companies adopting green innovations when such benefits are clearly perceived [37,38]. Technological compatibility, which refers to the degree to which an innovation aligns with existing values, beliefs and environmental needs, is shown to be essential for firms engaging in GIA [15,33].

From the organisational perspective, environmental corporate social responsibility (ECSR), innovation capability and organisational support are regarded as the key factors that promote innovation. ECSR can be understood as an organisational response to cognitive pressures. ECSR refers to a company's responsibilities toward internal stakeholders, top management, employees, customers, suppliers, business partners, communities and

interest groups [39]. It motivates organisations to evaluate the environmental consequences of their operations and mitigate adverse effects [39]. Innovation capability refers to a firm's capacity to identify new ideas and transform them into improved or novel products, services or processes that benefit the organisation [40]. It is an intrinsic factor that drives GI, helping to enhance a company's sustainability image and boost its efforts in GI [41]. Organisational support is a critical factor in determining the success of organisational innovation or change, as the implementation of innovation in a company is driven by internal factors such as structure, policies, culture and resources. Organisational encouragement of innovation and the support of innovation resources contribute to the advancement of technology [21].

From the environmental perspective, while literature has examined the impact of policy orientation on GI adoption, empirical evidence regarding the influence of environmental policies on GI adoption remains inconsistent. Policy orientation, which refers to the strategies, policy declarations, committee reports and scientific research that represent the will of the government [42]. It is considered to affect or induce the adoption of GI, as companies respond to policies (for ecological innovation practices) to get support and avoid potential legal liabilities and uncertainties [43,44]. Contrary to the positive effects, some researchers have drawn opposite conclusions, indicating that under the influence of China's fiscal decentralisation system and the "championship" system of political promotion, it significantly hinders corporate GIA [45,46]. Market pressure refers to the demands and expectations of end consumers and business clients, a key group of stakeholders that requires companies to improve their environmental and social performance [47]. Customers and business partners are considered stakeholders who can directly and indirectly exert pressure on organisations to adopt innovations [33]. With the growing awareness of environmental protection, eco-conscious customers are a key factor in encouraging companies to adopt GIs [43]. Nevertheless, some researchers have pointed out that in some cases, market pressure is not enough to promote GI [16,25]. It is crucial to examine how policy orientation and market pressure influence GIA under different contextual conditions.

2.4. Green Innovation Adoption and Cost Reduction

The existing literature suggests that firms' decisions to pursue GI are influenced by their internal cost-benefit considerations [48]. However, the financial implications of GIA remain a central yet contested topic in the literature. Some studies suggest that the adoption of GI can effectively lower relative costs by improving energy efficiency, reducing resource waste, and implementing differentiated product strategies [27,28]. Despite these positive findings, other scholars caution against overly optimistic expectations. Some researchers have argued that investments in green product innovation [30,49] and green process innovation [29] often lead to rapid shifts in production systems and operational protocols, which impose additional costs on firms and reduce their profitability. GIA may exacerbate cost burdens, as compliance expenses and capital requirements outweigh the immediate savings [30].

3. Hypotheses' Development

GIA is influenced by multiple contextual factors that collectively determine a firm's ability and willingness to integrate environmental considerations into its production and product development. Drawing on the TOE framework and insights from environmental economics theories such as Porter's hypothesis and the NRBV, this study develops and tests a series of hypotheses to explore how technological, organisational, and environmental factors influence green process and product innovations and how these innovations contribute to cost reduction.

3.1. Technological Context

Relative advantage has been shown to promote GI activities [50]. Previous studies suggest that the likelihood of adopting a given innovation increases as the relative advantage grows [13,33]. Relative advantage is shown to be a key factor in the adoption of cloud enterprise resource planning systems [51] and the Uber mobile application [52]. Technological compatibility is essential for firms engaging in GIA [15,33]. If GIA requires resources that the organisation lacks or entails changes misaligned with its strategy, implementation becomes highly challenging [13,33]. Based on these findings, four hypotheses are formulated:

H1a: *Relative advantage positively influences green process innovation.*

H1b: *Relative advantage positively influences green product innovation.*

H2a: *Technology compatibility positively influences green process innovation.*

H2b: *Technology compatibility positively influences green product innovation.*

3.2. Organisational Context

From the organisational perspective, the NRBV argues that companies can transform potential environmental threats into competitive advantages by effectively leveraging their resources and capabilities. The NRBV emphasises that an organisation's ability to successfully implement its environmental strategy depends on its ability to build and utilise resources better than its competitors [16]. Corporate environmental responsibility, characterised by proactive environmental management, plays a significant role in shaping GIA [53], with companies that prioritise external stakeholders, such as environmentally conscious customers, being more willing to invest in environmental initiatives [39]. Similarly, when a firm places strong emphasis on pollution control, ECSR leads to steady investment in green product and process innovation [54]. Thus, research suggests that ECSR significantly impacts environmental strategy, determining whether a company engages in GI [55].

Innovation capacity is essential for GIA, as companies need foundational knowledge and specialised skills to manage the associated organisational changes [13]. Green technology investment is costly, and pollution reflects inefficient resource use. Innovation capability enables firms to improve productivity, offsetting the costs of investments such as green product innovation [56]. Empirical research also indicates that innovation capability effectively promotes GIA [13,57].

When organisational readiness is high, employees are more likely to engage in change processes, facilitating the successful implementation of innovation [58,59]. Additionally, organisations that support green values are more likely to promote and apply green learning outcomes to accelerate GIA [60]. Moreover, clear environmental policies, cross-departmental coordination, and strong top management support, together with technological and financial readiness, are critical drivers of technological innovation [33]. Based on the above findings, the following hypotheses are proposed:

H3a: *ECSR positively influences green process innovation.*

H3b: *ECSR positively influences green product innovation.*

H4a: *Innovation capability positively influences green process innovation.*

H4b: *Innovation capability positively influences green product innovation.*

H5a: *Organisational support positively influences green process innovation.*

H5b: *Organisational support positively influences green product innovation.*

3.3. Environmental Context

According to Porter's hypothesis, appropriate and flexible environmental regulation will not only not harm the competitiveness of enterprises, but will instead motivate and promote enterprises to innovate and thus enhance their competitive strength [61]. This means that both coercive and normative pressures have a positive impact on GI. Thus, market pressure and policy orientation are regarded as the driving forces behind innovation practices. Researchers have noted that environmentally conscious customers are increasingly demanding energy-efficient and innovative green products [24,62], with many being willing to pay a premium for these offerings [62]. This demand incentivises companies to engage in green process and product innovation, since neglecting customer needs can lead to a loss of market share within the industry [24]. As more consumers adopt GI, a green network gradually forms [23], making it increasingly difficult for companies that do not implement GI to integrate with others, and thereby motivating enterprises to pursue GI.

Song et al. (2017) argue that the potential for GI within companies varies with changes in policy orientation [63]. Research by Stojčić (2021) indicates that public incentive policies such as government procurement, tax incentives, and subsidies actively promote corporate engagement in GI [44]. Additionally, Zhang et al. (2022) point out that various forms of government support, such as encouraging clean investments and increasing subsidies and financing channels, can foster renewable energy innovation [64]. Building on this research, the following hypotheses are formulated:

H6a: *Market pressure positively influences green process innovation.*

H6b: *Market pressure positively influences green product innovation.*

H7a: *Policy orientation positively influences green process innovation.*

H7b: *Policy orientation positively influences green product innovation.*

3.4. Green Innovation and Cost Reduction

According to ecological modernisation theory, GIA enhances a company's environmental productivity and reduces costs, thereby achieving an ecological-economic 'win-win' solution [65]. Scholars argue that GIA can lower corporate costs by avoiding raw material waste, reducing environmental costs and improving productivity [66,67]. For instance, companies can lower production costs by reducing environmental tax rates through GI [67]. Similarly, Wang et al. (2022) suggest that companies can avoid environmental penalties and save on raw materials by improving production processes, thus reducing waste disposal costs [68]. Therefore, two additional hypotheses are presented:

H8: *Green process innovation positively influences cost reduction.*

H9: *Green product innovation positively influences cost reduction.*

Figure 1 shows the research framework for this study.

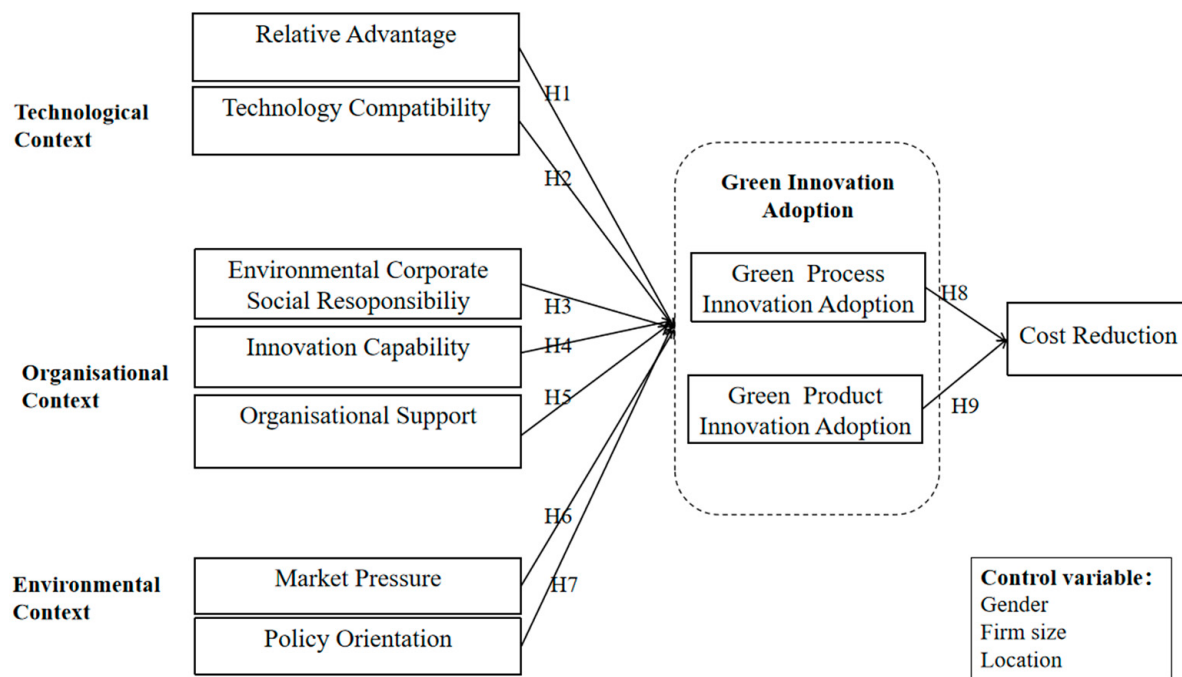


Figure 1. Research framework.

4. Research Method

4.1. Sample and Sampling Method

The construction industry is the largest contributor to energy consumption and carbon emissions in China, facing substantial pressure to improve energy efficiency and reduce emissions [2]. However, existing research on the drivers and outcomes of GI has primarily focused on the manufacturing sector. This study takes construction enterprises as the focal point of investigation. The minimum sample size was established using the G*Power tool version 3.1. The test employed a medium effect size ($f^2 = 0.15$, medium), an alpha of 0.05, and a power of 0.9 (According to [69], 0.8 often being regarded as the minimum acceptable power in social science studies). Since there were seven predictors in this study, a minimum sample size of 130 was required.

China's economic development exhibits significant regional disparities. Existing studies have shown that differences in firm size, ownership structure, region, etc., affect the implementation and effectiveness of GI [8,70,71]. This study employs a stratified random sampling approach, categorising firms by ownership type and region to ensure adequate representation across different types of enterprises. The stratified random sampling is basically based on the proportion of construction enterprises in each region (East, Central, West, and Northeast) in 2022. A survey conducted at the firm level was distributed, and a total of 277 valid questionnaires were collected after two rounds of mailing and follow-up phone calls. Among these, 134 were from SOEs and 143 from private enterprises. The participant recruitment period for this study was from 1 March to 10 July 2025. Table 1 shows the respondent demographics. The questionnaire included two screening questions: 'Are you currently working for a construction enterprise?' and 'Do you have any knowledge of green innovation adoption?' If respondents answered 'No' to either question, the survey was terminated, and their responses were marked as invalid to ensure data reliability. All participants were informed about the study's background, assured of their anonymity and confidentiality of the data and granted the right to withdraw their data within four weeks of completing the survey.

Table 1. Respondent's Demographics.

Demographic Characteristics	Percentage of Sample (SOE) (%) (<i>n</i> = 134)	Percentage of Sample (Private Enterprise) (%) (<i>n</i> = 143)
Gender		
Male	47	46.1
Female	52.9	53.8
Position		
Entrepreneur/owner	0.7	4.8
Top manager	8.9	13.2
Middle manager	41.7	42.6
Operational manager	2.9	3.4
Project manager	8.2	4.8
Supervisor	14.1	11.1
Others	23.1	19.5
Location		
East	57.4	51
Central	22.3	30
West	11.9	13.9
Northeast	8.2	4.8
Firm Age		
Less than 3 years	7.4	7.6
3–5 years	16.4	18.1
6–10 years	14.9	25.8
11–15 years	14.1	20.9
Over 15 years	47	39
Firm Size		
Large enterprises	26.8	15.3
Medium enterprises	58.9	61.5
Small enterprises	12.6	17.4
Micro enterprises	1.4	5.5

4.2. Instrument

All constructs were measured on a five-point Likert scale. The GIA-related questionnaires passed reliability and validity tests. The questionnaire included 38 items covering the technological, organisational and environmental factors affecting GIA, and its impact on cost reduction (see Appendix A). All constructs were modelled reflectively, with indicators treated as manifestations of latent concepts rather than as independent components. This approach was designed to capture respondents' perceptions of the constructs and is consistent with the majority of prior studies on GIA [72,73]. Cost reduction, adapted from [74], is measured using four items that capture decreases in raw material, waste disposal, and energy consumption costs. Green process innovation and green product innovation were each measured using four items that capture efforts such as inventing green products to enhance energy efficiency and establishing internal circulation systems, adapted from [75–78]. Technology compatibility was adapted from [13,79] and assessed through four items capturing its alignment with aspects such as operational requirements and customer needs. Innovation capability and relative advantage were each measured using three items, with the former adapted from [57,80], and the latter from [13]. Organisational support and ECSR are measured by four items, respectively. The former is adopted from [33,73], and the latter from [39,81]. Market pressure was measured by items capturing pressures from customers and supply chain partners, adapted from [82]. Policy orientation was measured by items reflecting financial, technical, and related government support, adapted from [82]. All collected data were entered into Smart PLS 4.0 for analysis. This

statistical approach effectively integrates measurement and structural models within a unified framework, allowing for comprehensive evaluation of latent constructs and their interrelationships [83].

5. Results

5.1. Measurement Model Analysis (SOEs)

The structural reliability and validity of measurement models for SOEs were assessed to ensure consistency and stability. This evaluation sought to assess how effectively measurements captured the intended variables based on their designated measurements. The measurement model comprised ten constructs: relative advantage, technology compatibility, ECSR, innovation capability, organisational support, market pressure, policy orientation, green product innovation, green process innovation and cost reduction. Loading refers to the correlation between latent structures and their respective items. An item loading is typically regarded as high if the loading coefficient exceeds 0.600 and low if it falls below 0.400 [84]. The lowest factor loading was 0.597 (CRed1) in the study, and the factor loading of the other indicators was higher than 0.6, which demonstrated satisfactory indicator reliability. Table 2 shows that every item was loaded on its own construct and surpassed the threshold value of 0.7 for composite reliability (Cronbach's alpha), which indicates that the measurement model has satisfactory internal consistency reliability. Additionally, the Average Variance Extracted (AVE) value for each variable was above the threshold of 0.5, indicating that the measurement model has sufficient convergent validity [85]. Discriminant validity is assessed using the Fornell–Larcker Criterion and Heterotrait–Monotrait Ratio (HTMT), which are widely used and accepted in the literature on green behaviour research [86]. Every latent variable shared more variance with its assigned indicators than with any other latent variable (Table 3), all HTMT values are below the recommended threshold of 0.90 (Table 4), indicating that the research model for SOEs had sufficient discriminant validity.

Table 2. Outer loadings, Reliability and VIF Values for SOEs.

Latent Variables	Indicators	Loadings	Cronbach's Alpha	AVE	VIF-Inner Model	VIF-Outer Model
Cost Reduction	CRed1	0.597	0.702	0.528		1.232
	CRed2	0.791				1.539
	CRed3	0.756				1.404
	CRed5	0.748				1.321
ECSR	ECSR1	0.674	0.722	0.546	1.847	1.323
	ECSR2	0.796				1.524
	ECSR4	0.797				1.566
	ECSR5	0.679				1.270
Green Process Innovation	GIA1	0.755	0.733	0.556	1.919	1.507
	GIA2	0.781				0.781
	GIA3	0.784				0.784
	GIA5	0.776				0.776
Green Product Innovation	GIA7	0.754	0.777	0.599	1.919	1.492
	GIA8	0.799				1.487
	GIA9	0.706				1.327
	GIA10	0.720				1.399
Innovation Capability	IC3	0.863	0.762	0.677	2.709	1.646
	IC6	0.764				1.412
	IC7	0.839				1.669
Market Pressure	MP1	0.745	0.719	0.541	2.600	1.436
	MP2	0.728				1.362
	MP3	0.767				1.362
	MP6	0.701				1.291

Table 2. Cont.

Latent Variables	Indicators	Loadings	Cronbach's Alpha	AVE	VIF-Inner Model	VIF-Outer Model
Organisational Support	OS1	0.780	0.763	0.584	3.251	1.518
	OS2	0.766				1.617
	OS4	0.796				1.592
	OS5	0.713				1.366
Policy Orientation	PO2	0.777	0.759	0.58	1.963	1.440
	PO3	0.756				1.522
	PO4	0.718				1.377
	PO5	0.794				1.549
Relative Advantage	RA1	0.799	0.724	0.644	1.890	1.412
	RA3	0.803				1.402
	RA5	0.806				1.460
Technology Compatibility	TCa1	0.757	0.706	0.531	2.254	1.364
	TCa2	0.719				1.322
	TCa3	0.779				1.498
	TCa5	0.654				1.260

Table 3. Fornell–Larcker Criteria test of the research model for SOEs.

Construct	1	2	3	4	5	6	7	8	9	10
1. CR	0.727 γ									
2. ECSR	0.453	0.739								
3. GPcI	0.596	0.574	0.746							
4. GpdI	0.594	0.430	0.692	0.774						
5. IC	0.412	0.554	0.507	0.579	0.823					
6. MP	0.539	0.577	0.566	0.560	0.684	0.736				
7. OS	0.426	0.57	0.422	0.531	0.737	0.665	0.764			
8. PO	0.459	0.544	0.566	0.591	0.547	0.581	0.615	0.762		
9. RA	0.537	0.449	0.470	0.530	0.483	0.592	0.612	0.446	0.803	
10. TC	0.573	0.557	0.611	0.545	0.471	0.594	0.642	0.590	0.582	0.729

Note. γ Square-root of AVE along the diagonal field; CR: cost reduction, ECSR: environmental corporate social responsibility, GPcI: green process innovation, GpdI: Green product Innovation, IC: innovation capability, MP: market pressure, OS: organisational support, PO: policy orientation, RA: relative advantage, TC: technology compatibility.

Table 4. Discriminant validity tests of the research model for SOEs (HTMT).

Construct	1	2	3	4	5	6	7	8	9	10
1. CR										
2. ECSR	0.615									
3. GPcI	0.806	0.781								
4. GpdI	0.794	0.565	0.889							
5. IC	0.555	0.742	0.660	0.752						
6. MP	0.747	0.794	0.765	0.741	0.893					
7. OS	0.575	0.774	0.549	0.682	0.898	0.887				
8. PO	0.615	0.722	0.742	0.764	0.713	0.789	0.807			
9. RA	0.764	0.610	0.631	0.707	0.661	0.826	0.831	0.605		
10. TC	0.805	0.777	0.831	0.727	0.641	0.842	0.894	0.809	0.822	

Note. CR: cost reduction, ECSR: environmental corporate social responsibility, GPcI: green process innovation, GpdI: Green product Innovation, IC: innovation capability, MP: market pressure, OS: organisational support, PO: policy orientation, RA: relative advantage, TC: technology compatibility.

5.2. Measurement Model Analysis (Private Enterprises)

The reliability and validity of measurement models for private enterprises were also evaluated. The outer loading of all reserved items was higher than 0.6 [84,87], and the composite reliability (Cronbach's alpha) of all constructs was higher than 0.7 (Table 5), which demonstrates satisfactory indicator reliability and internal consistency reliability [85]. The discriminatory validity of these constructs was verified using the Fornell–Larcker

criteria (Table 6) and HTMT (Table 7). These parameters are indicated to emphasise the credibility and applicability of the model's findings. Potential collinearity issues with the structural model were evaluated before the evaluation. Tables 2 and 5 show that there is no collinearity issue with any of the indicators and constructs in this study, as the VIF (collinearity statistics) values of all items and constructs are less than 5 [85]. To assess the potential impact of common method variance bias (CMVB), Harman's single-factor test was conducted. The results revealed that no single factor accounted for more than 40% of the variance in both models, suggesting that CMVB is not a serious concern.

Table 5. Outer Loadings, Reliability and VIF Values for Private Enterprises.

Latent Variables	Indicators	Loadings	Composite Reliability (Cronbach's Alpha)	AVE	VIF-Inner Model	VIF-Outer Model
Cost Reduction	CRed1	0.722	0.713	0.533		1.629
	CRed2	0.773				1.587
	CRed3	0.723				1.409
	CRed5	0.701				1.178
Environmental Corporate Social Responsibility	ECSR1	0.707	0.786	0.610	2.508	1.340
	ECSR2	0.799				1.607
	ECSR4	0.815				1.670
	ECSR5	0.799				1.717
Green Process Innovation	GIA1	0.736	0.702	0.527	1.921	1.388
	GIA2	0.717				1.371
	GIA3	0.771				1.454
	GIA5	0.730				1.329
Green Product Innovation	GIA7	0.748	0.723	0.546	1.921	1.384
	GIA8	0.751				1.330
	GIA9	0.677				1.292
	GIA10	0.727				1.361
Innovation Capability	IC3	0.807	0.728	0.647	2.479	1.516
	IC6	0.816				1.466
	IC7	0.791				1.357
Market Pressure	MP1	0.766	0.805	0.630	2.041	1.733
	MP2	0.790				1.709
	MP3	0.815				1.780
	MP6	0.802				1.750
Organisation Support	OS1	0.787	0.754	0.574	2.308	1.488
	OS2	0.773				1.413
	OS4	0.720				1.427
	OS5	0.748				1.454
Policy Orientation	PO2	0.773	0.811	0.639	1.985	1.749
	PO3	0.861				2.104
	PO4	0.807				1.789
	PO5	0.752				1.431

Table 5. *Cont.*

Latent Variables	Indicators	Loadings	Composite Reliability (Cronbach's Alpha)	AVE	VIF-Inner Model	VIF-Outer Model
Relative Advantage	RA1	0.805	0.727	0.647	2.223	1.437
	RA3	0.808				1.429
	RA5	0.799				1.422
Technology Compatibility	TCa1	0.802	0.737	0.559	2.241	1.512
	TCa2	0.727				1.331
	TCa3	0.800				1.553
	TCa5	0.650				1.284

Table 6. Fornell–Larcker Criteria tests of the research model for private enterprises.

Construct	1	2	3	4	5	6	7	8	9	10
1. CR	0.730									
2. ECSR	0.540	0.781								
3. GPcI	0.519	0.691	0.726							
4. GpdI	0.592	0.619	0.692	0.739						
5. IC	0.451	0.679	0.636	0.582	0.805					
6. MP	0.427	0.641	0.560	0.556	0.601	0.793				
7. OS	0.480	0.58	0.510	0.594	0.641	0.543	0.757			
8. PO	0.470	0.542	0.543	0.535	0.598	0.534	0.625	0.799		
9. RA	0.519	0.561	0.542	0.525	0.574	0.478	0.609	0.548	0.804	
10. TC	0.613	0.621	0.635	0.639	0.528	0.56	0.567	0.454	0.655	0.748

Note. γ Square-root of AVE along the diagonal field; CR: cost reduction, ECSR: environmental corporate social responsibility, GPcI: green process innovation, GpdI: Green product Innovation, IC: innovation capability, MP: market pressure, OS: organisational support, PO: policy orientation, RA: relative advantage, TC: technology compatibility.

Table 7. Discriminant validity tests of the research model for private enterprises (HTMT).

Construct	1	2	3	4	5	6	7	8	9	10
1. CR										
2. ECSR	0.698									
3. GPcI	0.696	0.890								
4. GpdI	0.797	0.811	0.898							
5. IC	0.609	0.895	0.885	0.799						
6. MP	0.543	0.790	0.736	0.719	0.775					
7. OS	0.647	0.745	0.697	0.792	0.872	0.694				
8. PO	0.607	0.671	0.715	0.691	0.782	0.660	0.805			
9. RA	0.718	0.732	0.758	0.725	0.793	0.622	0.825	0.712		
10. TC	0.846	0.797	0.859	0.867	0.715	0.723	0.759	0.579	0.894	

Note. CR: cost reduction, ECSR: environmental corporate social responsibility, GPcI: green process innovation, GpdI: Green product Innovation, IC: innovation capability, MP: market pressure, OS: organisational support, PO: policy orientation, RA: relative advantage, TC: technology compatibility.

5.3. Structural Model Comparison Analysis Between State-Owned and Private Enterprises

Table 8 provides path coefficient (β) values, their statistical significance and the results of hypothesis testing. From the table, we can observe that in the SOE context, 10 pathways are significant, with 9 hypotheses supported. Unexpectedly, organisational support shows a negative effect on GIA. In the private enterprise context, 6 pathways are significant, with 6 hypotheses supported (see Figures 2 and 3).

Table 8. Structural Model for Both State-Owned and Private Enterprises.

No.	Variable Relationship	State-Owned			Private		
		Path Coefficient	Results	f-Square	Path Coefficient	Results	f ²
H1a	RA → GPcI	Not significant	Rejected	-	Not significant	Rejected	-
H1b	RA → GPdI	0.215 *	Supported	0.050	Not significant	Rejected	-
H2a	TCa → GPcI	0.358 *	Supported	0.128	0.283 **	Supported	0.088
H2b	TCa → GPdI	Not significant	Rejected	-	0.316 **	Supported	0.098
H3a	ECSR → GPcI	0.223 *	Supported	0.060	0.309 **	Supported	0.093
H3b	ECSR → GPdI	Not significant	Rejected	-	Not significant	Rejected	-
H4a	IC → GPcI	0.257 *	Supported	0.055	0.215 *	Supported	0.046
H4b	IC → GPdI	0.330 *	Supported	0.082	Not significant	Rejected	-
H5a	OS → GPcI	-0.420 **	Rejected	-	Not significant	Rejected	-
H5b	OS → GPdI	Not significant	Rejected	-	Not significant	Rejected	-
H6a	MP → GPcI	Not significant	Rejected	-	Not significant	Rejected	-
H6b	MP → GPdI	Not significant	Rejected	-	Not significant	Rejected	-
H7a	PO → GPcI	0.224 *	Supported	0.057	Not significant	Rejected	-
H7b	PO → GPdI	0.297 *	Supported	0.092	Not significant	Rejected	-
H8a	GPcI → CRed	0.355 ***	Supported	0.113	0.210 *	Supported	0.037
H8b	GPdI → CRed	0.348 ***	Supported	0.109	0.447 ***	Supported	0.166

Note. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; CRed = Cost Reduction; GPcI = Green Process Innovation; GPdI = Green Product Innovation; ECSR = Environmental Corporate Social Responsibility; IC = Innovation Capability; MP = Market Pressure; OS = Organisational Support; PO = Policy Orientation; RA = Relative Advantage; TCa = Technology Compatibility.

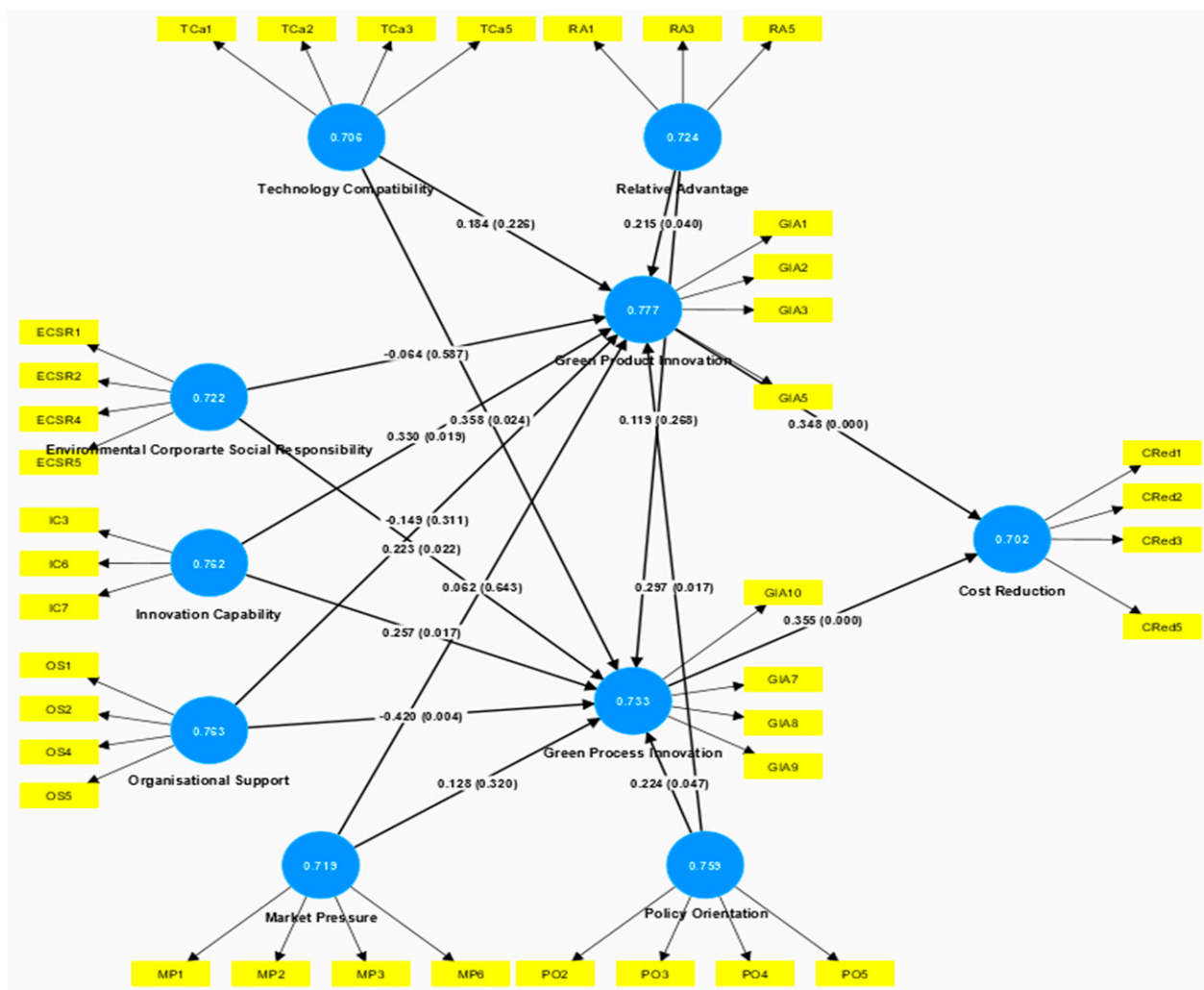


Figure 2. Structural model (SOEs). Note. Constructs: Cronbach's alpha; Inner model: Path coefficients and *p*-values.

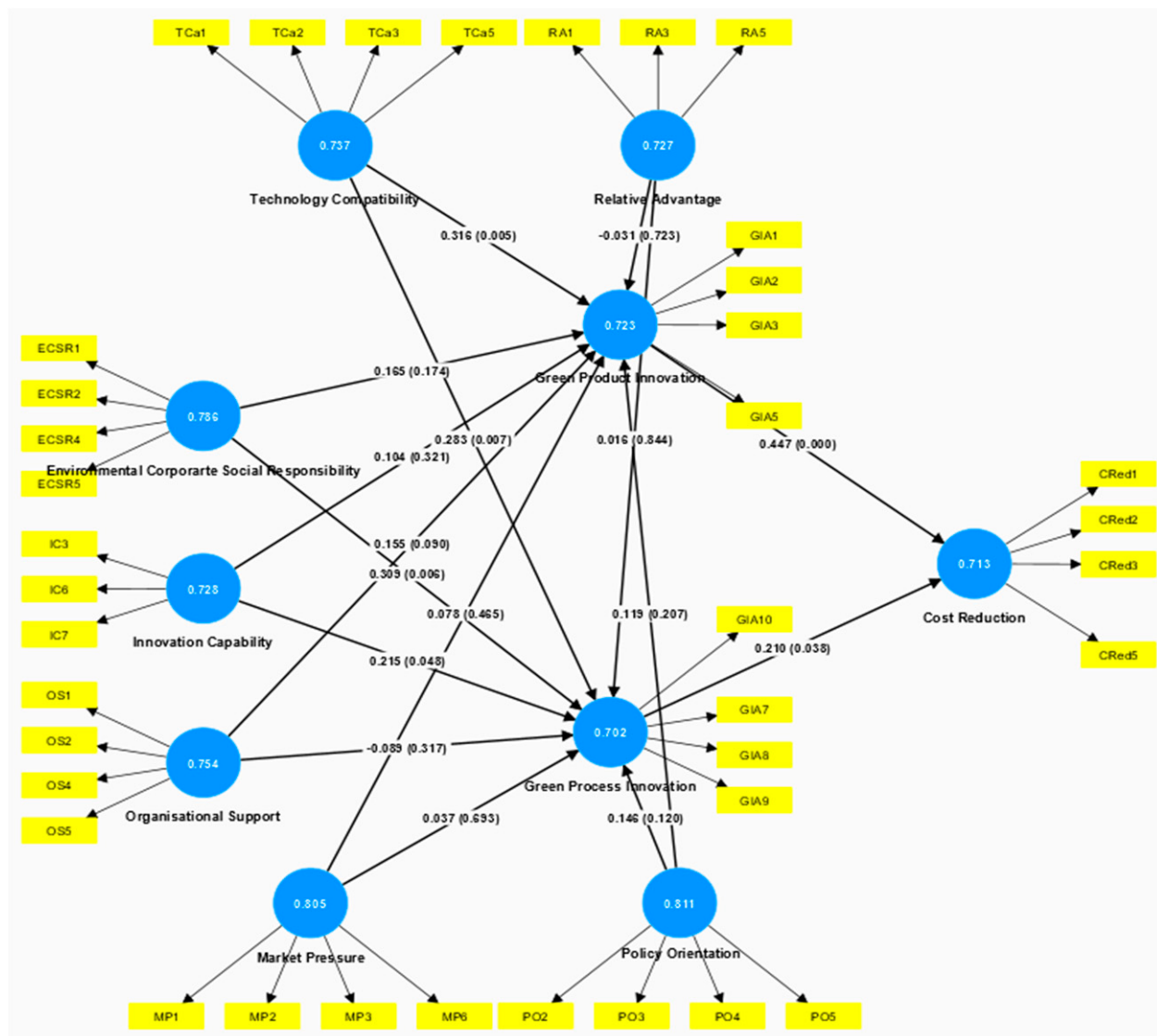


Figure 3. Structural model (private enterprises). Note. Constructs: Cronbach's alpha; Inner model: Path coefficients and *p*-values.

The study further evaluated the model's predictive power. As presented in Table 9, the structural model explained 41.8% of cost reduction, 55.4% of green process innovation, and 50.9% of green product innovation among SOEs. For private enterprises, it accounted for 37.4% of cost reduction, 59.3% of green process innovation, and 54.7% of green product innovation. All R^2 values exceeded the 0.26 benchmark, indicating strong predictive capacity. Moreover, all Q^2 values were greater than zero, confirming predictive relevance. The effect sizes (f^2) of the independent variables, which capture their relative influence on the dependent variables, ranged from 0.037 to 0.166, corresponding to small-to-moderate effects according to established thresholds of 0.02 (small), 0.15 (medium), and 0.35 (large). The standardised root mean square residual (SRMR) was 0.077 for SOEs and 0.075 for private enterprises, both below the 0.08 threshold, indicating a satisfactory model fit.

Table 9. Predictive power measures.

Dependent Variable	Ownership	R ²	Q ²
Cost Reduction	SOE	0.418	0.190
	Private enterprise	0.374	0.176
Green Process Innovation	SOE	0.554	0.273
	Private enterprise	0.593	0.288
Green Product Innovation	SOE	0.509	0.276
	Private enterprise	0.547	0.273

5.4. Multiple-Group Analysis

To assess whether the study findings are applicable to specific sample groups and whether structural path differences exist between these groups, a multi-group analysis (MGA) was conducted comparing SOEs and private enterprises using the same model. Prior to the multi-group analysis, measurement invariance was assessed using the Measurement Invariance Assessment (MICOM) procedure in SmartPLS 4. Compositional invariance was confirmed by the initial correlation values being greater than or equal to 5%, with a permutation p -value exceeding 0.05. Table 10 presents the MICOM results, which confirmed compositional invariance across both groups (permutation test, $p > 0.05$), indicating that the constructs were measured equivalently and that cross-group comparisons are valid.

Table 10. MICOM results.

Variable	Original Correlation	5.00%	Permutation p Value	Compositional Invariance?
Cost Reduction	1.000	0.986	0.969	Yes
ECSR	0.999	0.994	0.858	Yes
Green Process Innovation	0.999	0.995	0.809	Yes
Green Product Innovation	1.000	0.997	0.761	Yes
Innovation Capability	0.997	0.996	0.087	Yes
Market Pressure	0.999	0.994	0.799	Yes
Organisational Support	0.995	0.991	0.227	Yes
Policy Orientation	0.998	0.994	0.516	Yes
Relative Advantage	1.000	0.992	0.997	Yes
Technology Compatibility	1.000	0.994	0.906	Yes

A PLS-MGA was then conducted using non-parametric methods, specifically the permutation test. Calculations were based on 5000 permutations with a significance level set at $p < 0.05$. A p -value less than 0.05 indicates significant differences between the SOE and private enterprise samples. Table 11 presents the results of the permutation test. The results revealed a significant difference in the relationship between organisational support and green process innovation ($p < 0.05$), suggesting that this relationship varies significantly between SOEs and private enterprises. Other relationships showed no statistically significant differences, suggesting that the overall model structure was largely stable across ownership types. Consistent with prior research [88,89], it is common for only a limited number of paths to exhibit statistically significant differences. Nevertheless, the direction and magnitude of the path coefficients offer meaningful insights into ownership-specific dynamics within the model.

Table 11. Permutation test results.

Variable	Path Coefficients (SOE)	Path Coefficients (Private Enterprise)	Path Coefficients Difference	2.50%	97.50%	Permutation <i>p</i> Value
ECSR → GPcI	0.309	0.223	0.086	−0.296	0.292	0.577
ECSR → GPdI	0.165	−0.064	0.229	−0.382	0.380	0.247
GPcI → CRed	0.210	0.355	−0.145	−0.271	0.266	0.295
GPdI → CRed	0.447	0.348	0.099	−0.256	0.264	0.465
IC → GPcI	0.215	0.257	−0.042	−0.308	0.310	0.794
IC → GPdI	0.104	0.330	−0.226	−0.395	0.399	0.301
MP → GPcI	0.037	0.128	−0.091	−0.293	0.289	0.544
MP → GPdI	0.078	0.062	0.016	−0.334	0.334	0.926
OS → GPcI	−0.089	−0.420	0.331	−0.319	0.330	0.045
OS → GPdI	0.155	−0.149	0.304	−0.379	0.383	0.124
PO → GPcI	0.146	0.224	−0.078	−0.281	0.278	0.600
PO → GPdI	0.119	0.297	−0.178	−0.358	0.345	0.334
RA → GPcI	0.016	0.119	−0.103	−0.273	0.263	0.488
RA → GPdI	−0.031	0.215	−0.245	−0.295	0.278	0.097
TCa → GPcI	0.283	0.358	−0.075	−0.359	0.348	0.716
TCa → GPdI	0.316	0.184	0.132	−0.390	0.379	0.515

Note. CRed = Cost Reduction; GPcI = Green Process Innovation; GPdI = Green Product Innovation; ECSR = Environmental Corporate Social Responsibility; IC = Innovation Capability; MP = Market Pressure; OS = Organisational Support; PO = Policy Orientation; RA = Relative Advantage; TCa = Technology Compatibility.

6. Discussion

6.1. Discussion and Implications

6.1.1. Theoretical Implications

Utilising the TOE model, this study compared the differences between SOEs and private enterprises in the construction industry in terms of the impact of contextual factors on GIA and the impact of GIA on cost reduction. The study makes several theoretical contributions to research on GIA. First, by integrating the TOE framework with institutional theory and NRBV, this study systematically examines the impact of technological, organisational, and environmental factors on construction enterprises' GIA, and provides a more refined analytical framework tailored to the GI landscape of China's construction enterprises. Second, while existing research focuses on the manufacturing industry, this study fills a critical gap in research on GI behaviour within the construction industry. Third, this study highlights the unique influence of ownership on technological innovation decisions, addressing the lack of regard for different ownership types of enterprises within GI research in the construction industry. Fourth, against the backdrop of ongoing academic debate, this study further investigates the relationship between GIA and cost reduction with different ownership structures, the inconsistent role of market pressure and policy orientation on GIA.

6.1.2. Discussion and Managerial Implications

The results indicate that GIA contributes positively to cost reduction in both types of enterprises, accounting for 41.8% of the cost reduction in SOEs and 37.4% in private enterprises. Through GIA, firms can reduce material and energy consumption, enhance recycling practices to improve energy efficiency, utilise environment-related tax rebates, and other supportive policies to offset the additional costs of GIA. These findings align with prior evidence, including [27] in the Chinese context and [28] in the United Arab Emirates context, demonstrating that, for both state-owned and private construction enterprises, GI offers an effective strategy to achieve environmental improvement while simultaneously reducing costs [27,28]. However, Wong et al. (2020) argue that while green process innovation can lower costs by improving resource efficiency, green product innovation in

China incurs high expenses and may not yield sufficient differentiation effects; rather than reducing costs, it may lead to further expenses [30]. The inconsistency in research findings may be attributed to firms' innovation potential. More technologically advanced companies are more likely to leverage innovation to address cost-increasing policy measures; hence, leading innovators often achieve greater cost reductions than their less innovative counterparts [90].

In China's construction industry, market pressure exerts no significant influence on GIA of either SOEs or private enterprises, challenging the institutional theory proposition that organisational decisions are shaped by normative pressures such as market demand. It is inconsistent with existing literature, such as [23,24]. The finding aligns with [16,25]. Thomas et al. (2021) indicated that market pressure stemming from customers, suppliers and investors does not significantly influence the GIA of innovative Italian SMEs [25]. Due to uncertainties such as high costs, significant risks, and long payback periods, GI activities are often approached cautiously [91]. In addition, in the Chinese context, most companies engage in GIA primarily in response to environmental policies [12]. These two factors weakened the impact of market pressure on GIA. While Afum et al. (2023) argue that market orientation often fails to align with critical organisational implementation practices, as market-oriented firms tend to place relatively limited emphasis on sustained R&D investment in Ghana [16]. This misalignment helps explain why market pressure may be insufficient to stimulate GIA in emerging economies [16].

Policy orientation positively influences the GIA of SOEs, while having no significant effect on private enterprises. Partially consistent with the conclusions of this study, some studies conducted in Egypt, Germany, etc., also showed that policy orientation did not significantly affect GIA [26,92,93]. However, these studies did not discuss the impact of differences in ownership structure on the results. This study fills the gap in research in this area. Due to the majority state share, SOEs face more stringent governmental mandates and social responsibilities [6]. In addition, SOEs are more likely to benefit from government favouritism [94], and large-scale, abundant funds, low financing constraints and easier access to government funding [95] make SOEs more sensitive to policy orientation. With higher financing constraints [95] and financial constraints [94], private enterprises show low willingness to respond when policy incentives are insufficient to compensate for the high costs and risks of GIA. Therefore, the government should alleviate the financial pressure at the initial stage of private enterprises' GIA by means of green technological reform subsidies and R&D funding to improve the relative economic attractiveness of GIA and decrease its risk and uncertainty.

Innovation capability serves as the key driver for SOEs in pursuing both green process innovation and green product innovation. This further validates the NRBV perspective within the context of China's construction industry. Regarding innovation capability, this study corroborates the research of [57] from Romania and [13] from China. Technology compatibility exerts no significant influence on green product innovation in SOEs. In contrast, its effect size on green process innovation reaches 0.128, indicating that, when technology compatibility improves, SOEs tend to prioritise green process innovation. Moreover, ECSR positively influences green process innovation in SOEs, but not green product innovation, because engaging in the latter involves more cost [96]. Governments should cultivate a societal culture that prioritises green development and incentivise SOEs to embrace ECSR, thereby fostering GI in the construction industry. However, organisational support has no significant effect on green product innovation in SOEs, but exerts a negative influence on green process innovation (Permutation p value = 0.045), with an effect size (f^2 = 0.122) approaching a medium magnitude. Scholar argues that although the call to advance green buildings has gained broad support within the construction industry, the absence of effec-

tive mechanisms to identify non-adopters and monitor firms' actual practices constrains the diffusion of GI across the sector [36]. Since GI is fraught with uncertainty, the construction industry in particular has a long payback period, and Chinese enterprises are heavily influenced by the need for environmental compliance [12]. One possible explanation is that some SOEs may engage in greenwashing practices to secure government funding or policy support, which undermines their motivation for green process innovation [97]. Since SOEs are sensitive to policy orientation, it is suggested that the government should strengthen their supervision of GI behaviour in construction enterprises to prevent greenwashing. Life cycle assessments, which evaluate a building's environmental impact from cradle to grave, and third-party-verified environmental product declarations, which provide transparent data on product impacts, have emerged as key regulatory instruments [98].

For private enterprises, green product innovation is influenced by technology compatibility, while green process innovation is affected by technology compatibility, ECSR and innovation capabilities. However, the impact of the relative advantage and organisational support on GIA is shown to be limited for private firms. Inconsistent with the conclusions of this study, existing literature suggested a significant positive correlation between organisational support and GIA [33,99], as well as relative advantage and GIA in the context of countries and regions such as Malaysia [33,38]. This may be because private firms do not benefit from the same level of government support as SOEs, and they have greater financial burdens imposed on them [94,95]. Green product innovation represents a higher level of innovation, potentially requiring new production lines and incurring greater costs [96]. To control costs, private enterprises are more inclined to adopt GI on the premise of having sufficient technological compatibility. The finding is supported by [13]. The government should promote the construction of green technology service platforms to reduce the difficulty of technology integration in private enterprises, which will help them integrate green technologies smoothly. In addition, given the critical role of ECSR and innovation capability in driving green process innovation among private enterprises, they should enhance their innovation capacity and ECSR by building joint R&D platforms and alliances to reduce their innovation risks and costs, and government departments need to create conditions for this.

6.2. Limitations and Recommendations of Research

This study employed a questionnaire survey method combined with the TOE framework to investigate the similarities and differences in GIA between SOEs and private enterprises. The findings provide insights for policy and management practices in GIA. Limitations of the study include, first, potential statistical biases stemming from unequal group sizes and limitations of sample size. Prior studies have suggested that a sufficiently large sample can reduce the potential biases caused by unequal group sizes [100]. However, the imbalance between groups may still introduce distortions in the results. Future research can improve the robustness of the study by using larger and more balanced sample sizes. Second, this study only used closed questions to obtain information. Future research should consider incorporating qualitative methods and secondary data to gain a deeper and more credible understanding of GIA. This facilitates a clearer understanding of the underlying reasons for accepting or rejecting the hypothesis [101]. For instance, the observed negative effect of organisational support on GIA in SOEs may be linked to the persistence of greenwashing practices. However, this interpretation remains speculative and warrants further empirical validation. Third, although this study measured all constructs through reflective modelling, some of these constructs (e.g., policy orientation, organisational support) may have the potential for formative operationalisation. Future research could consider using formative indicators to capture their multidimensional nature. Fourth, the results may

reflect the specific time frame in which the study was conducted. The findings of the study deviate to some extent from previous research, indicating that researchers should look at longitudinal studies to explore the changing trends of key factors influencing GIA in China's SOEs and private enterprises. Fifth, the research was limited to construction enterprises in China. This restricts the generalizability of the findings, and future research could extend the analysis to other regions or industries. Cross-country comparisons of construction enterprises with different ownership structures could provide insights for the development and investment in GIA at an international level.

7. Conclusions

This study, grounded in TOE theory, NRBV, and institutional theory, developed an extended TOE model to compare the impact of technological, organisational and environmental factors on GIA between SOE and private enterprise and to assess the role of GIA in reducing costs in these enterprises. Sixteen hypotheses were proposed, with results showing that in the SOEs context, ten paths are significant and nine hypotheses supported; in private enterprises, six hypotheses are supported. The findings indicate that GIA (including green process and product innovation) significantly reduces costs in both SOEs and private enterprises. However, market pressure has no significant impact on GIA in either ownership structure. This may be attributed to the substantial investment requirements and prolonged payback periods associated with GIA in the construction industry, which diminishes the influence of market pressure on GIA. To address this, governments should ease firms' financial burdens during the early stages of GI through targeted subsidies and dedicated R&D funding.

In SOEs, GIA is mainly influenced by technology compatibility, relative advantages, innovation capabilities, ECSR, organisational support and policy orientation. Notably, organisational support negatively impacts green process innovation in SOEs. This may be due to short-term greenwashing behaviour to secure government funding or policy support, which can diminish the motivation for substantial green process innovation [97]. The government should strengthen oversight of greenwashing in SOEs by employing regulatory tools such as life cycle assessments and third-party-verified environmental product declarations [98]. In private enterprises, GIA is influenced by technology compatibility, ECSR and innovation capabilities. Governments and enterprises should enhance technology compatibility, strengthen ECSR, and build innovation capacity in private enterprises by establishing green technology service systems and collaborative R&D platforms.

This research is among the few studies focusing on GIA within the construction industry and one of the rare comparative studies employing a questionnaire survey to investigate the impact of GIA on cost reduction in enterprises with different ownership structures. It indicates the differences in key contextual factors influencing the GIA of SOEs and private enterprises. The findings offer valuable insights to guide corporate decision-making on GIA and to inform the formulation of more effective policies. This study is subject to certain limitations, including reliance on a single research method, unequal group sizes, and restricted generalizability of the findings. Future research could enhance the credibility and broader applicability of the results by employing mixed-method approaches, using larger and more balanced group sample sizes, and extending analyses across different regions and industries.

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Institutional Review Board Statement: The study was approved by the Universiti Malaya Research Ethics Committee(UMREC)(protocol code UM.TNC2/UMREC_3250, date of approval: March 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The dataset generated and analysed in this study is not publicly available. The dataset is available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Measurements.

Variables	Items	Sources
Cost Reduction	CRed1: After applying green innovation, the cost for materials purchasing of the company has decreased over the last 3 years.	[74]
	CRed2: After applying green innovation, the cost for energy consumption of the company has decreased during the last 3 years.	
	CRed3: After applying green innovation, the cost on waste disposal of the company has decreased during the last 3 years.	
	CRed5: After applying green innovation, the fine for environmental accidents of the company has decreased during the last 3 years.	
Green Innovation Adoption	GIA1: Our firm's emphasis on developing new green products (such as green buildings).	[75,76]
	GIA2: Our firm develops new green products to recycle.	
	GIA3: Our firm develops new green products that easily decompose their materials.	
	GIA5: Our firm develops new green products to use as little energy and resources as possible.	
	GIA7: Our firm has a recycling system in the construction process.	[75,77,78]
	GIA8: Our firm updates operating processes to meet the standards of environmental law.	
	GIA9: Our firm uses innovative technologies in its operating processes to save energy and resources (e.g., water, electricity, fuel).	
	GIA10: Our firm reduces the emission of hazardous substances or waste during the construction process.	
	TCa1: The technologies adopted for green innovation meet our operational needs.	[13,79]
	TCa2: The technologies adopted for green innovation match the requirements of suppliers/customers.	
	TCa3: The technologies adopted for green innovation are compatible with our existing green practices.	
	TCa5: The technologies adopted for green innovation are easy to integrate with a company's existing system.	
Relative Advantage	RA1: The technologies adopted for green innovation increase operational efficiency.	[13]
	RA3: The technologies adopted for green innovation reduce the cost of resources.	
	RA5: The technologies adopted for green innovation can provide higher economic benefits.	

Table A1. Cont.

Variables	Items	Sources
Organisational support	OS1: Our firm has the infrastructure to implement the technologies adopted for green innovation.	[33,73]
	OS2: Our firm has skilled workers to manage green innovation.	
	OS4: Our firm provides rewards for employees' green behaviour.	
	OS5: Top management in my firm provides adequate resources to support green innovation.	
Innovation Capability	IC3: Our firm has the courage to try new ways of taking green action.	[57,80]
	IC6: Our firm commits to green innovation implementation.	
	IC7: Our firm has a long-term strategy to invest in green innovation.	
Environmental Corporate Social Responsibility	ECSR1: We are committed to not using natural resources that are in danger of depletion.	[39,81]
	ECSR2: Our firm participates in activities that aim to protect and improve the quality of the natural environment.	
	ECSR4: Our firm conforms to the requirements of environmental management.	
	ECSR5: Our firm respects and protects the natural environment.	
Market Pressure	MP1: Our down/upper stream suppliers expect our firm to adopt green innovation.	[82]
	MP2: Our shareholders/investors expect our firm to adopt green innovation.	
	MP3: Our customers expect us to adopt green innovation.	
	MP6: Customer green demands stimulate us in our environmental efforts.	
Policy Orientation	PO2: The government provides financial support for adopting green innovation.	[102]
	PO3: The government provides technical assistance for adopting green innovation.	
	PO4: The government provides tax-saving measures for adopting green innovation.	
	PO5: There is legislation that protects companies to adopting green technologies.	

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