

Article

Beyond External Pressure: Executive Green Cognition as an Internal Governance Mechanism for Corporate Green Transformation

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Abstract

Despite stringent environmental regulations, the divergence between private costs and social benefits frequently induces symbolic rather than substantive firm compliance. This study investigates Executive Green Cognition (EGC) as an internal mechanism to mitigate this distortion. Using a text-based index derived from Management Discussion and Analysis (MD&A) disclosures of Chinese listed firms (2010–2024), we demonstrate that higher EGC significantly facilitates corporate green transition by enhancing both green innovation output and Total Factor Productivity. Supporting the micro-foundations of the Porter Hypothesis, we find that these productivity gains coincide with reduced Carbon Emission Intensity (CEI), thereby ruling out scale expansion effects. Mechanism tests indicate that EGC reduces agency costs by reallocating resources from non-productive defensive expenditures to substantive green investments. Furthermore, digital transformation positively moderates this relationship by lowering implementation costs. These findings highlight EGC as a critical micro-foundation for shifting firms from passive compliance to endogenous sustainable development.

Keywords: executive green cognition; green transformation; green agency cost; green information disclosure; digital transformation

1. Introduction

Global climate change has transitioned green development from a normative ethical concern to a critical determinant of international economic competitiveness. As the world's largest developing economy, China's pledge to reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060 necessitates a structural transition from factor-driven growth toward high-quality, resource-efficient development [1]. As the primary organizational units of this transition [2], firms face a fundamental decision-making dilemma: the misalignment between the private costs of environmental protection and the social benefits of emission reduction generates positive externalities. Consequently, profit-maximizing firms typically exhibit under-investment in green initiatives [3]. While extensive research emphasizes the mandatory role of external regulatory instruments, such as environmental taxes and command-and-control policies [4,5], in correcting these market failures, empirical evidence reveals a persistent discrepancy between policy objectives and implementation outcomes [6]. In response to regulatory pressure, many firms

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engage in strategic compliance or deceptive environmental signaling, resulting in symbolic adoption rather than substantive green transformation [7]. This phenomenon motivates the core research question of this study: Beyond external regulatory pressure, what are the organizational determinants and internal mechanisms that drive firms to transition from passive compliance to proactive structural reconfiguration?

Executive Green Cognition is defined as the attentional allocation and strategic priority senior management assigns to environmental protection and sustainable development [8]. Grounded in upper echelons theory, the extant literature identifies executive cognitive structures as critical determinants of strategic choices [9]. Specifically, elevated EGC facilitates resource allocation toward green technological innovation and carbon mitigation [10–12], while aligning corporate behaviors with stakeholder demands to enhance social legitimacy [13]. Prior research predominantly adopts an external governance perspective, positing that external institutional pressures act as essential boundary conditions for converting cognition into action [14–17]. Specifically, studies indicate that government regulation increases non-compliance costs by internalizing environmental externalities; media supervision strengthens reputational constraints by mitigating information asymmetry; and market competition compels firms to respond to stakeholder pressures to sustain competitive advantage [18]. However, this stream of literature often assumes a linear translation of cognitive traits into organizational outcomes under strong external governance, thereby overlooking complex internal intertemporal agency conflicts, notably risk aversion. These internal structural barriers impede capital allocation toward long-term sustainable projects, leaving a theoretical void regarding why firms facing identical external regulatory intensities exhibit heterogeneous strategic responses [19]. To address this gap, this study shifts the analytical focus from a descriptive external pressure–response association to a functional internal governance mechanism. We conceptualize EGC as a governance instrument that mitigates agency problems, arguing that without the internal governance function of cognition, relying solely on external institutional pressures is insufficient to explain substantive corporate transformation. By reallocating managerial attention and recalibrating the managerial utility function, EGC effectively reduces the intertemporal agency costs associated with green investment, thereby constituting the critical micro-foundation that bridges strategic intent and substantive corporate action.

This study constructs the Executive Green Cognition (EGC) index using textual analysis of annual reports from Chinese A-share listed firms between 2010 and 2024. To ensure data validity, we extract text exclusively from the Management Discussion and Analysis (MD&A) sections rather than voluntary Corporate Social Responsibility (CSR) reports [20]. Unlike voluntary disclosures, the MD&A is subject to strict statutory liability, thereby mitigating the risk of greenwashing and more accurately reflecting genuine strategic intent [21].

To rigorously define corporate green transition, we depart from unidimensional metrics such as Green Total Factor Productivity (GTFP) and adopt a dual-dimensional framework comprising green innovation output and Total Factor Productivity (TFP) [22]. We argue that a sustainable transition must align with the Porter Hypothesis, where environmental regulations trigger innovation offsets sufficient to neutralize compliance costs. Empirically, we demonstrate that EGC simultaneously enhances technical innovation and productive efficiency, effectively distinguishing proactive restructuring from passive compliance. A distinct feature of this study is the validation of the Porter Hypothesis through this dual framework. While the prior literature frequently relies on GTFP, this metric endogenously incorporates environmental outputs, making it analytically difficult to disentangle pure efficiency gains from environmental performance. We posit that sustainable green transition requires an innovation offset mechanism that compensates for

compliance costs while simultaneously achieving environmental improvement and economic competitiveness. Consequently, we operationalize green transition through two synergistic dimensions: (1) Environmental Dimension (Green Innovation Output): Measured by green patent applications, this proxy captures substantive efforts in process restructuring and source control. (2) Economic Dimension (Total Factor Productivity): We employ TFP as a direct proxy for innovation offsets [23].

To address potential endogeneity, particularly reverse causality arising from endogenous matching between firms and executives, we employ the historical carbon emissions of executives' birthplaces as an instrumental variable (IV). This identification strategy leverages the imprinting theory of cognitive formation to isolate exogenous variation in executive cognition, independent of current local institutional confounders.

The results provide robust evidence that Executive Green Cognition (EGC) significantly advances corporate green transition. Mechanism tests indicate that this effect is transmitted through a causal chain proceeding from governance optimization to signaling, and ultimately to resource reallocation. First, executives with high green cognition mitigate green agency conflicts by curtailing non-productive defensive expenditures, such as symbolic end-of-pipe treatments intended for image maintenance. Second, they enhance the quality of environmental disclosures, thereby reducing information asymmetry and financing frictions. Third, these efficiency gains facilitate the redirection of capital toward substantive green investments, including R&D and equipment upgrades.

However, possessing a high level of executive green cognition constitutes a necessary but insufficient condition for successful green transformation. The translation of executive strategic intent into organizational outcomes is frequently impeded by internal friction and high implementation costs. Even with strong environmental commitment, executives face challenges in effectively reallocating resources due to information asymmetry and organizational rigidity. We identify corporate digital transformation as a critical moderating factor to address these barriers. The integration of digital technologies, such as Big Data, AI, and IoT, creates a synergistic convergence with environmental strategies [24], a dynamic increasingly conceptualized in the literature as the twin transition of digitalization and decarbonization [25]. Specifically, these technologies restructure the firm's operational capabilities by integrating data elements, which lowers the marginal cost of information processing and environmental management. We propose that digital infrastructure and executive green cognition operate as complements. While EGC dictates the firm's strategic trajectory, digital transformation ensures the requisite operational capacity for the execution of such strategies. Consequently, digital transformation strengthens the link between cognition and action by enhancing the responsiveness of green innovation and productivity to executive cognitive directives.

The marginal contributions of this study are threefold. First, we shift the analytical focus from external institutional constraints to internal cognitive governance. By conceptualizing EGC as a mechanism that mitigates agency conflicts and alleviates managerial myopia, we elucidate the micro-foundations of intra-firm environmental decision-making. Second, we provide a rigorous micro-level test of the Porter Hypothesis by demonstrating that Executive Green Cognition (EGC) drives parallel improvements in green innovation and Total Factor Productivity (TFP). Crucially, we validate the environmental substantiveness of these efficiency gains by documenting a concurrent reduction in Carbon Emission Intensity (CEI). This finding precludes the alternative explanation that productivity growth stems from pollution-intensive scale expansion, thereby confirming the compatibility of environmental performance and economic value during the firm's green transition. Third, we identify the distinct transmission mechanisms driving substantive investment as opposed to symbolic compliance, offering policy implications for stimulating endogenous motivation for decarbonization in emerging markets.

2. Literature Review and Hypotheses Development

2.1. Executive Green Cognition and Green Transformation

In the context of global climate change mitigation, the determinants of corporate green transformation have emerged as a focal point in environmental economics and corporate finance research. Existing literature generally aligns with two theoretical frameworks: external institutional constraints and internal cognitive foundations.

The external perspective emphasizes the role of regulatory pressure. Regulations impose constraints through emission standards and taxation mechanisms, while green financial instruments allocate capital toward environmental projects [26,27]. Additionally, stakeholder pressure promotes corporate environmental responsibility via reputational incentives [28,29]. However, the prevalence of symbolic compliance highlights the limitations of relying exclusively on external regulation. Although external pressures establish minimum compliance standards [30], they often fail to resolve internal agency conflicts or alleviate managerial myopia, leading to limited substantive change. While the Porter Hypothesis suggests that well-designed regulations can trigger innovation offsets to compensate for compliance costs [31], empirical evidence remains mixed. A critical limitation in the literature is the tendency to treat the firm as a homogenous unit, assuming uniform responses to regulatory shocks. In practice, strategic non-compliance is common, characterized by the adoption of superficial measures, such as end-of-pipe treatments, rather than substantive structural changes. Consequently, external pressure appears to be a necessary but insufficient condition for genuine green transformation.

To construct a comprehensive theoretical framework, this study integrates Upper Echelons Theory with Behavioral Agency Theory. Upper Echelons Theory posits that strategic choices reflect the cognitive structures and values of the Top Management Team (TMT) [32]. As the primary strategic decision-makers, executives utilize specific cognitive frameworks to interpret complex information and guide organizational practices [33,34]. In this study, Executive Green Cognition (EGC) is defined as the level of attention and strategic priority that senior management allocates to environmental protection within the decision-making process [8]. This cognitive orientation shapes firm behavior, as the backgrounds and values of executives determine their environmental sensitivity, which subsequently influences the strategic direction and operational conduct of the firm [9]. Incorporating behavioral agency logic, we propose that EGC reconfigures the managerial utility function regarding risk. While traditional agency models suggest managers are risk-averse toward long-term R&D, high EGC internalizes environmental externalities, thereby increasing the subjective utility derived from sustainable outcomes. Specifically, rather than passively accepting environmental regulations as mandatory costs, executives with high green cognition interpret environmental issues as strategic opportunities for growth [35]. By integrating social responsibility into long-term strategic objectives [35], they direct capital allocation toward green technological innovation and the optimization of environmental management systems [36].

Consequently, EGC functions as a primary internal governance mechanism that enables firms to overcome path dependence and replace end-of-pipe treatments with proactive process improvements [18,37]. This structural shift simultaneously enhances environmental performance and Total Factor Productivity through innovation offsets, thereby driving corporate green transformation.

Based on these considerations, this article proposes the following hypotheses:

H1. *Executive green cognition has a significant positive effect on corporate green transformation.*

2.2. *The Mechanism of Executive Green Cognition Affecting Corporate Green Transformation*

The prior literature typically examines these drivers in isolation; in contrast, this study proposes an integrated and sequential framework. Theoretically, internal governance restructuring serves as the antecedent condition, as the mitigation of agency conflicts is requisite for firms to generate credible information signals. Subsequently, the resulting reduction in information asymmetry facilitates the acquisition of external resources, which are then allocated toward substantive green investments. Consequently, we posit that Executive Green Cognition (EGC) drives transformation through a sequential pathway of “Governance Optimization—Signaling—Resource Reallocation.”

2.2.1. Executive Green Cognition, Green Agency Costs and Green Transformation

The impediments to corporate green transformation stem fundamentally from agency conflicts regarding environmental objectives rather than solely from capital constraints [38,39]. The transition to green development represents a structural challenge of intertemporal resource allocation. Green investments are inherently characterized by high ex ante uncertainty, extended payback periods, and significant positive social externalities [40]. These attributes create a misalignment between the firm’s long-term sustainability interests and the risk-averse, short-term preferences of agents. This phenomenon, which we term the Green Agency Conflict, precipitates managerial myopia and frequently results in defensive expenditures or symbolic compliance rather than substantive commitment [41].

In the absence of effective governance, risk-averse managers prioritize low-risk, defensive outlays to satisfy minimum regulatory requirements rather than allocating capital to radical green innovation [42]. We acknowledge that Executive Green Cognition serves as an internal governance mechanism that alleviates this myopia. By internalizing environmental externalities into the managerial utility function, executive green cognition aligns executive incentives with sustainable development goals [26,43,44]. This cognitive orientation fosters a normative commitment that suppresses opportunistic rent-seeking behavior while simultaneously equipping executives with the environmental expertise necessary to identify and eliminate non-productive expenditures [45,46]. Consequently, enhanced executive green cognition minimizes resource dissipation and redirects capital toward substantive green innovation, thereby securing the innovation offsets required for genuine transformation [47,48].

Based on this reasoning, we propose the following:

H2. *Executive green cognition promotes corporate green transformation by reducing green agency costs.*

2.2.2. Executive Green Cognition, Green Information Disclosure and Green Transformation

Executives possessing high green cognition employ information disclosure as a strategic tool to ameliorate market imperfections. In contrast to firms relying on symbolic environmental management, Executive Green Cognition (EGC) reorients the function of disclosure from regulatory compliance to a mechanism for signaling underlying firm quality [49,50]. However, the credibility of this signal is contingent upon the internal governance environment. In the presence of high agency costs, managers are prone to opportunistic behaviors, including the strategic manipulation of environmental data, which compromise the reliability of reported information [51]. EGC mitigates this risk by aligning managerial incentives with long-term sustainability objectives. As agency conflicts are alleviated, the managerial incentive to withhold negative environmental information dimin-

ishes. Consequently, executives are motivated to enhance the transparency and substantiveness of environmental reporting to accurately communicate the firm's fundamental value to capital markets [21,52]. This signaling mechanism reduces information asymmetry and financing frictions [53], thereby facilitating the acquisition of external resources necessary for transformation [6]. Furthermore, high-quality disclosure exerts a disciplinary influence on internal operations. The commitment to transparent reporting enhances external monitoring and necessitates the standardization of environmental management systems, specifically regarding data tracking and process optimization [54–56]. This internal standardization subsequently strengthens the organizational framework required for effective green transformation.

Therefore, we propose the following:

H3. *Executive green cognition promotes corporate green transformation by improving the quality of green information disclosure.*

2.2.3. Executive Green Cognition, Green Investment and Green Transformation

The realization of green transformation fundamentally hinges on substantive resource reallocation. While reduced agency costs and enhanced disclosure establish necessary preconditions, specifically governance efficiency and financial slack, green investment constitutes the decisive mechanism converting these inputs into productivity gains.

According to the Resource-Based View, heterogeneous resources form the foundation of competitive advantage [57]. However, traditional capital budgeting is often subject to intertemporal choice bias that hinders the financing of high-tech green projects. Executive Green Cognition mitigates this friction. Through cognitive framing, executives are better able to recognize the real option value of green technologies [58] and maintain strategic commitment despite ex ante uncertainty. Following the optimization of internal governance and the relaxation of financing constraints, EGC facilitates the redirection of capital from carbon-intensive activities toward green R&D and equipment upgrades [59,60].

Distinct from symbolic adoption, such substantive investment targets core operational domains and fundamentally alters the firm's production function [61]. The resulting accumulation of specialized assets, such as proprietary technologies, creates barriers to imitation and yields simultaneous improvements in environmental performance and Total Factor Productivity [62]. Consequently, green investment functions as the proximal channel through which cognitive advantages materialize into sustainable competitive advantages.

Based on this, we propose the following:

H4. *Executive green cognition promotes corporate green transformation by increasing substantive green investment.*

2.3. Executive Green Cognition, Digital Transformation and Green Transformation

Digital transformation fundamentally reshapes organizational production functions and governance structures through the integration of data elements. While the extant literature predominantly examines the direct impact of digitalization on total factor productivity [44], this study adopts a Resource Orchestration perspective to explore its contingent role. We argue that digital transformation functions as a critical governance infrastructure that alleviates the friction inherent in translating executive cognition into organizational outcomes. Specifically, it acts as a complementary mechanism that lowers the marginal cost of implementing environmental strategies, thereby enhancing the elasticity of corporate green transformation with respect to executive green cognition.

Regarding governance capacity, digital technologies augment the monitoring and resource orchestration capabilities of the Top Management Team (TMT) [28]. This technological integration reduces the marginal cost of implementing environmental decisions, ensuring that cognitive intent is efficiently translated into process optimization. Second, concerning information efficiency, digitalization lowers internal and external information processing costs. Consistent with Lee et al. (2025) [63], who find that information sharing determines policy efficacy, highly digitized firms exhibit superior transparency. In such environments, executive strategic intent is more effectively transmitted internally and made visible to external investors [64]. This transparency amplifies the signaling effect of executive green cognition, thereby alleviating financing constraints and attracting external capital to support transformation.

Crucially, we posit that digital capabilities and executive cognition function as complements rather than substitutes. Digital infrastructure serves as a tool that reduces the transaction costs of strategy implementation but does not inherently dictate strategic direction [65]. For executives with high green cognition, digital platforms provide precise environmental data that mitigates information asymmetry, thereby facilitating the conversion of latent cognitive preferences into active resource commitment. Conversely, in the absence of green cognition, digital tools are equally liable to be deployed for non-environmental objectives [6]. Consequently, digitalization increases the elasticity of green transformation with respect to executive green cognition.

Based on this reasoning, we propose the following:

H5. *The level of corporate digital transformation positively moderates the promoting effect of executive green cognition on corporate green transformation.*

3. Methodology

3.1. Data Sources

The sample comprises Chinese A-share listed companies spanning the period from 2010 to 2024. Carbon emission data, financial and corporate governance data are sourced from the CSMAR database, while green innovation data are obtained from the CNRDS database. Executive green cognition data are constructed via textual analysis of annual reports.

We apply standard data filtering procedures: (1) excluding firms under special treatment status (ST, *ST) or delisted during the sample period; (2) excluding the financial sector due to distinct accounting standards; and (3) removing observations with missing values for key variables. To mitigate the influence of outliers, all continuous variables are winsorized at the 1st and 99th percentiles. The final sample consists of 49,101 firm-year observations.

3.2. Model Construction

To estimate the impact of executive green cognition on corporate green transformation, we specify the following two-way fixed effects model:

$$GT_{it} = \beta_0 + \beta_1 EGC_{it} + \gamma X_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (1)$$

where i and t denote the firm and year, respectively. The dependent variable, GT_{it} , represents corporate green transformation of firm i in year t , measured by green innovation (G_Innov) and total factor productivity (TFP_LP , TFP_OP). The core independent variable, EGC_{it} , denotes executive green cognition. X_{it} represents a vector of control variables. μ_i and η_t encompass firm and year fixed effects, controlling for time-invariant firm heterogeneity and time-specific common shocks. Standard errors are clustered at the firm level.

3.3. Variables

3.3.1. Core Independent Variable: Executive Green Cognition (EGC)

Following established methodologies in the literature, we quantify Executive Green Cognition (EGC) using textual analysis [66–68]. We posit that the frequency of environment-related terminology proxies for the cognitive attention the Top Management Team (TMT) allocates to green development. We compile a keyword dictionary covering three dimensions: green competitive advantage, external environmental pressure, and corporate social responsibility (see Appendix A Table A1 for details). The variable *EGC* is calculated as the natural logarithm of one plus the total frequency of these keywords in the Management Discussion and Analysis (MD&A) section. We focus exclusively on the MD&A section rather than voluntary CSR disclosures to minimize the risk of symbolic disclosure. As a mandatory reporting requirement governed by statutory liability, the MD&A more accurately reflects substantive strategic orientation and resource allocation decisions. Therefore, it serves as a valid proxy for executive cognitive commitment [20,21].

3.3.2. Dependent Variable: Green Transformation (GT)

Conventional environmental management typically relies on end-of-pipe abatement technologies. While effective for regulatory adherence, these measures function primarily as additive compliance costs. In contrast, substantive green transformation requires the joint optimization of environmental performance and economic efficiency, achieved through induced technological innovation and organizational restructuring. Following Deng et al. (2024), we operationalize corporate green transformation through two dimensions [23]: (1) Green Innovation Output (*G_Innov*): Measured by the natural logarithm of the number of green invention patent applications plus one, representing substantive technological output. This metric captures the technological dimension and functions as the fundamental driver of the transition. Through the development of green technologies, firms implement source reduction mechanisms, thereby facilitating a structural shift from traditional energy-intensive production toward cleaner operational paradigms. (2) Efficiency Improvement (*TFP*): Measured by Total Factor Productivity. To ensure robustness and correct for simultaneity bias in production function estimation, we employ both the Levinsohn and Petrin (2003) (LP) and Olley and Pakes (1996) (OP) semi-parametric methods, denoted as *TFP_OP* and *TFP_LP*, respectively [69,70]. *TFP* represents the efficiency dimension and reflects the economic viability of the transformation. Consistent with the Porter Hypothesis, successful green transformation generates innovation offsets, wherein induced innovation compensates for compliance costs and enhances overall productivity. Therefore, a firm is considered to have achieved genuine transformation, as opposed to mere regulatory compliance, only when it demonstrates both green technological output and improved production efficiency.

To rigorously preclude the alternative explanation that efficiency gains are achieved at the expense of environmental performance, we examine the impact of *EGC* on Carbon Emission Intensity (*CEI*). The observation of a simultaneous increase in *TFP* and decrease in *CEI* provides the necessary identification condition to confirm that productivity improvements stem from environmentally sustainable practices.

3.3.3. Other Control Variables

To isolate the effect of executive cognition, we control for the following firm characteristics:

- (1) Firm Size (*Size*): The natural logarithm of total assets at year-end;
- (2) Leverage (*Lev*): The ratio of total liabilities to total assets;
- (3) Cash Flow (*Cashflow*): Net operating cash flow divided by total assets;

- (4) Ownership Concentration (Top10): The proportion of shares held by the top ten shareholders;
- (5) Board independence (Indep): The ratio of independent directors to the total number of board members;
- (6) Firm Age (ListAge): The natural logarithm of the number of years since listing plus one;
- (7) Management Age (TMTAge): The average age of directors, supervisors, and senior executives;
- (8) Gender Diversity (*Female*): The proportion of female members in the TMT.

Descriptive statistics for the main variables are presented in Table 1.

Table 1. Descriptive statistics.

Var.	Obs.	Mean	St.Dev	Min	Median	Max
EGC	49,101	3.204	4.344	0.000	2.000	22.000
G_Innov	49,101	0.876	1.180	0.000	0.000	4.804
TFP_OP	49,101	6.716	0.901	2.558	6.603	12.607
TFP_LP	49,101	8.939	1.113	4.557	8.824	14.354
Size	49,101	22.202	1.295	19.478	21.996	26.452
Lev	49,101	0.416	0.209	0.028	0.406	0.934
Cashflow	49,101	0.045	0.069	−0.226	0.045	0.266
Top10	49,101	0.583	0.156	0.195	0.592	0.910
Indep	49,101	0.384	0.074	0.231	0.375	0.615
ListAge	49,101	2.049	0.943	0.000	2.197	3.466
TMTAge	49,101	49.374	3.243	40.600	49.440	57.890
Female	49,101	0.202	0.116	0.000	0.188	0.579

4. Results

4.1. Validity Test and Benchmark Regression

To address concerns that the text-based EGC index might capture symbolic greenwashing rather than genuine cognition, we conducted a validity test. Following the validation framework established by Hassan et al. (2019), we posit that valid cognitive measures should be correlated with executives' prior knowledge and experience [71]. Accordingly, we manually compile data on the environmental backgrounds (Env_BG) of TMT members, defined as the possession of academic degrees in environmental science or professional experience in environmental protection agencies (Detailed construction procedures are provided in Supplementary Material S1). Results reported in Appendix A Table A2 (Column 1) indicate that firms led by executives with such domain-specific backgrounds exhibit significantly higher EGC. This finding validates the index as a reliable proxy for the unobservable cognitive structure of management.

Table 2 presents the baseline estimates of Equation (1). Columns (1), (3), and (5) report the univariate regressions, while Columns (2), (4), and (6) include the full set of firm-level controls. The results show that the coefficient on *EGC* is positive and statistically significant at the 1% or 5% level across all specifications. Specifically, a one-unit increase in Executive Green Cognition is associated with a statistically significant increase in both Green Innovation Output (*G_Innov*) and Total Factor Productivity (*TFP_OP* and *TFP_LP*), supporting Hypothesis 1.

Table 2. Benchmark Regression Results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	G_Innov	G_Innov	TFP_OP	TFP_OP	TFP_LP	TFP_LP
EGC	0.013 *** (0.002)	0.012 *** (0.002)	0.003 ** (0.001)	0.002 ** (0.001)	0.005 *** (0.001)	0.004 *** (0.001)
Size		0.000 *** (0.000)		0.000 *** (0.000)		0.001 *** (0.000)
Lev		0.334 *** (0.053)		0.439 *** (0.049)		0.685 *** (0.056)
Cashflow		−0.006 (0.064)		0.821 *** (0.055)		0.874 *** (0.058)
Top10		0.686 *** (0.095)		0.740 *** (0.071)		1.039 *** (0.082)
Indep		−0.011 (0.061)		0.037 (0.039)		0.005 (0.042)
ListAge		0.040 ** (0.016)		−0.043 *** (0.009)		−0.028 *** (0.011)
TMTAge		0.011 *** (0.003)		0.001 (0.002)		0.007 ** (0.003)
Female		−0.249 *** (0.082)		−0.023 (0.061)		−0.088 (0.068)
Constant	0.195 *** (0.019)	−0.949 *** (0.174)	6.374 *** (0.012)	5.628 *** (0.129)	8.516 *** (0.013)	7.187 *** (0.141)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	49,101	49,101	49,101	49,101	49,101	49,101
Adj_R ²	0.180	0.191	0.206	0.250	0.217	0.280

Note: Standard errors clustered in firm level are in parentheses; **, and *** indicate significant at the 5%, and 1% levels, respectively.

To mitigate the concern that our measure captures symbolic disclosure rather than substantive cognition, we augment the baseline specification with a Greenwashing (GW) covariate. Following Hu et al. (2023), we construct GW to proxy for the discrepancy between disclosure and performance, defined as the interaction term between nominal disclosure and substantive outcome dummies (detailed construction procedures are provided in Supplementary Material S2) [72]. The econometric identification relies on the premise that if the EGC index were merely a proxy for symbolic behavior, its explanatory power would be absorbed by the GW variable upon inclusion. However, the results in Appendix A Table A2 (Columns 2–4) indicate that the coefficient on EGC remains robustly positive, while the coefficient on GW is significantly negative. These findings confirm that EGC captures unobservable cognitive factors that are orthogonal to symbolic compliance and serve as positive drivers of green transformation.

4.2. Endogeneity Issue and Robustness Checks

While the baseline estimates establish a positive association, causal inference is complicated by potential endogeneity arising from omitted variable bias or reverse causality. Specifically, this includes endogenous assortative matching, where environmentally proactive firms are more likely to select executives with high green cognition. To address these identification challenges, we employ three complementary strategies: Instrumental Variable (IV) estimation, the Heckman two-stage selection model, and Propensity Score Matching (PSM).

4.2.1. Instrumental Variable Method

To mitigate endogeneity concerns, we employ the historical carbon emissions of the executive's birthplace (BirthCO2_Hist) as an instrumental variable (IV). Following the imprinting hypothesis, we define the critical period for cognitive formation as ages 10 to 24, which corresponds to the period 1971–1985 for the average executive in our sample. Based on Upper Echelons Theory, we argue that early-life environmental conditions condition individual cognition. Consequently, historical local emissions serve as a proxy for exposure to environmental externalities. Exposure to severe degradation in high-emission areas heightens environmental risk perception through the mechanism of negative experience memory, thereby inducing a stronger green cognitive orientation [73–75].

To satisfy the exclusion restriction, we exclude observations where the firm's registered location coincides with the executive's birthplace. This geographical separation is methodologically critical to decouple the cognitive channel from local confounders such as social capital, political ties, or regional industrial endowments. This design ensures that historical environmental conditions influence current corporate behavior primarily through internalized cognition rather than external resource dependencies. We further control for executives' political connections (Pol_Con) and educational background (Aca_Bg) to rule out alternative social capital channels. Finally, to disentangle the specific effect of pollution exposure from regional economic development, we augment the model with historical socioeconomic indicators, specifically GDP per capita (GDPpc) and the share of the secondary industry (Ind_Structure) during the imprinting period.

The instrument satisfies the exogeneity assumption through temporal separation and orthogonality. First, the 1971–1985 period strictly predates our sample window, thereby precluding reverse causality as current corporate strategies cannot influence historical emissions. Second, historical emissions in the executive's birthplace are orthogonal to the contemporaneous regulatory environment and market conditions of the firm's current location. Furthermore, as a long-term outcome of regional industrialization, the instrument is uncorrelated with firm-specific characteristics such as size or industry during the sample period, thus mitigating omitted variable bias.

We maintain that birthplace emissions affect firm outcomes exclusively through the executive cognition channel. As an objective historical characteristic of the executive's origin, this variable does not directly endow the firm with green technologies or policy resources, nor does it alter financing constraints or factor allocation. Consequently, the instrument satisfies the exclusion restriction by influencing corporate green innovation and productivity solely through the mechanism of executive green cognition.

Table 3 reports the 2SLS estimation results using BirthCO2_Hist as the instrumental variable. First-Stage and Diagnostics: The first-stage estimates indicate that BirthCO2_Hist is positively associated with EGC at the 5% significance level, satisfying the instrument relevance condition consistent with the imprinting hypothesis. Diagnostic tests confirm the validity of the instrument. Specifically, the Cragg–Donald and Kleibergen–Paap rk Wald F-statistics are 276.74 and 79.60, respectively; both exceed the critical values established by Stock and Yogo (2005), thereby rejecting the null hypothesis of weak identification [76]. Furthermore, the Kleibergen–Paap rk LM statistic is statistically significant, rejecting the null hypothesis of underidentification. These metrics collectively attest to the robustness of our identification strategy.

Table 3. IV Regression Results.

Variables	(1)	(2)	(3)	(4)	(5)
	First Stage	Second Stage	Second Stage	Second Stage	Placebo Test
	EGC	G_Innov	TFP_LP	TFP_OP	Non-G_Innov
BirthCO2_Hist	0.292 ** (0.143)				
EGC		0.242 * (0.132)	0.115 * (0.069)	0.124 * (0.068)	0.081 (0.063)
GDPpc	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 ** (0.000)
Ind_Structure	0.012 (0.008)	0.002 (0.005)	0.001 (0.003)	0.001 (0.003)	0.004 (0.004)
Pol_Con	0.004 (0.029)	0.006 (0.010)	0.009 (0.006)	0.012 * (0.006)	0.009 (0.011)
Ack_Bg	0.012 (0.029)	0.002 (0.011)	0.016 *** (0.006)	0.017 *** (0.006)	−0.003 (0.012)
Cragg-Donald Wald F			276.74 [16.38]		
Kleibergen-Paap rk Wald			79.60 [16.38]		
Kleibergen-Paap rk LM			7.744 **		
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	40,018	40,018	40,018	40,018	40,018

Note: Standard errors clustered in firm level are in parentheses; *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

The second-stage results demonstrate that the instrumented EGC exerts a significant and positive effect on G_Innov. Similarly, the coefficients for Total Factor Productivity (TFP_LP and TFP_OP) are positive and statistically significant. These findings substantiate a causal interpretation, suggesting that executive green cognition improves resource allocation efficiency and drives substantive corporate green transformation.

To further validate the exclusion restriction and rule out the hypothesis that the instrument captures general risk preferences or unobserved managerial traits rather than domain-specific green cognition, we conduct a placebo test. We estimate the impact of the instrumented EGC on non-green innovation output. The results indicate that the coefficient is statistically indistinguishable from zero. This null result regarding non-green outcomes supports the argument that historical environmental exposure selectively influences environmental awareness, rather than altering generalized risk-taking behavior or overall innovative propensity.

4.2.2. Heckman's Two-Stage Estimation

To address potential endogeneity arising from sample selection bias, we employ the Heckman two-stage correction model. In the first stage, we estimate a Probit regression to model the probability of a firm exhibiting high Executive Green Cognition (EGC).

To satisfy the exclusion restriction, we specify the mean executive green cognition of industry peers (Ind_Peer_EGC) as the instrumental variable in the selection equation. This variable is defined as the average EGC of other firms within the same industry-year co-

hort. We posit that peer behavior exerts normative pressure on corporate decision-making, thereby satisfying the relevance condition. Crucially, while industry-level cognitive norms influence the focal firm's strategic adoption, they are arguably orthogonal to the firm's idiosyncratic innovation output or production efficiency shocks, thus satisfying the exogeneity condition.

Table 4 reports the estimation results. The first-stage Probit estimates show that *Ind_Peer_EGC* carries a significantly positive coefficient, confirming the instrument's relevance. In the second-stage outcome equation, after controlling for the Inverse Mills Ratio (IMR) to correct for selection bias, the coefficient on EGC remains positive and statistically significant for both Green Innovation (*G_Innov*) and Total Factor Productivity (*TFP_LP* and *TFP_OP*). These findings indicate that the estimated impact of executive green cognition on corporate green transformation is robust to selection bias correction.

Table 4. Heckman's Two-stage Estimation Results.

Variables	(1)	(2)	(3)	(4)
	EGC	G_Innov	TFP_LP	TFP_OP
Ind_Peer_EGC	2.907 *** (0.028)			
EGC		0.011 *** (0.002)	0.002 * (0.001)	0.004 *** (0.001)
IMR		5.580 *** (0.526)	0.167 (0.330)	0.061 (0.375)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	49,101	49,101	49,101	49,101
Adj_R ²	0.853	0.199	0.250	0.280

Note: Standard errors clustered in firm level are in parentheses; *, and *** indicate significant at the 10%, and 1% levels, respectively.

4.2.3. PSM Method

To mitigate estimation bias arising from selection on observables, we employ the Propensity Score Matching (PSM) approach. We first define a binary treatment indicator, assigning a value of 1 to firms with EGC levels at or above the industry average (treatment group), and 0 otherwise (control group). Propensity scores are estimated via a Probit model incorporating all baseline covariates. Subsequently, we implement a 1:1 nearest neighbor matching algorithm within a 0.01 caliper to ensure comparability between treated and control units.

Post-matching diagnostics reported in Table 5 demonstrate that the covariate balance is well satisfied. The standardized mean differences for all covariates are reduced to below 2%. Furthermore, t-tests fail to reject the null hypothesis of equality between groups ($p > 0.10$), confirming that the matching process effectively removes observable systematic differences.

Table 5. Balance Test Results.

Variable	Mean		% Bias	t-Test
	Treated	Control		Pvalue
Size	22.452	22.458	−0.500	0.647
Lev	0.438	0.441	−1.300	0.229
Cashflow	0.047	0.047	0.300	0.804

Top10	0.585	0.584	0.700	0.506
Indep	0.381	0.381	1.100	0.299
ListAge	2.130	2.139	−0.900	0.395
TMTAge	49.838	49.794	1.400	0.204
Female	0.193	0.193	−0.300	0.780

Re-estimating the baseline model using the matched sample, we find that the coefficient on EGC for corporate green innovation (G_Innvo) is 0.014 in Table 6. Similarly, the coefficients for total factor productivity (TFP_LP and TFP_OP) are 0.003 and 0.005, respectively. These estimates corroborate the robustness of our primary conclusion that executive green cognition acts as a substantive determinant of both innovation output and production efficiency.

Table 6. PSM Estimation Results.

Variables	(1)	(2)	(3)
	G_Innov	TFP_LP	TFP_OP
EGC	0.014 *** (0.003)	0.003 ** (0.001)	0.005 *** (0.001)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	24,301	24,301	24,301
Adj_R ²	0.200	0.257	0.289

Note: Standard errors clustered in firm level are in parentheses; **, and *** indicate significant at the 5%, and 1% levels, respectively.

4.3. Other Robustness Checks

4.3.1. Alternative Measurements

To verify the robustness of our main findings, we perform a series of sensitivity analyses using alternative metrics for both independent and dependent variables. Specifically, we (1) re-operationalize the independent variable using EGC_Ratio, defined as the proportion of green cognition-related words in the full text, to mitigate measurement bias associated with document length; (2) employ the count of granted green invention patents (G_Innov_gran) as a proxy for innovation quality; (3) re-estimate Total Factor Productivity using OLS, Fixed Effects (FE), and GMM estimators to address potential specification bias; (4) adopt the Corporate Green Transformation Index (GT_Index) following Zhou et al. (2022) as an alternative outcome variable [77]; and (5) introduce Carbon Emission Intensity (CEI), measured as total carbon emissions scaled by operating revenue, to verify that the transformation translates into substantive environmental performance beyond technical efficiency.

Table 7 reports the estimation results utilizing the alternative independent variable (EGC_Ratio). The coefficient on EGC_Ratio for Green Innovation (G_Innov) is positive and statistically significant (coefficient = 5.456, $p < 0.01$). Similarly, the estimates for TFP_OP and TFP_LP are positive and significant (2.084 and 2.461, respectively; $p < 0.05$). These findings are consistent with our baseline estimates, confirming that the positive impact of executive green cognition is robust to alternative specifications of the explanatory variable.

Table 7. Robustness check 1: Replacing Independent Variable Measurement Method.

Variables	(1)	(2)	(3)
	G_Innov	TFP_OP	TFP_LP
EGC_Ratio	5.456 *** (1.366)	2.084 ** (0.845)	2.461 ** (0.962)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	49,101	49,101	49,101
Adj_R ²	0.111	0.161	0.198

Note: Standard errors clustered in firm level are in parentheses; **, and *** indicate significant at the 5%, and 1% levels, respectively.

Table 8 reports the regression results employing alternative outcome measures. The coefficient of EGC is 0.020 for Granted Green Patents (G_Innov_gran) and 0.082 for the Green Transformation Index (GT_Index). Additionally, TFP estimates derived from OLS, Fixed Effects (FE), and GMM specifications remain statistically significant at the 1% level. Crucially, the coefficient of EGC on Carbon Emission Intensity (CEI) is negative and significant at the 1% level, indicating that executive green cognition effectively induces a reduction in carbon intensity.

Table 8. Robustness check 2: Replacing Dependent Variable Measurement Method.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	G_Innov_Gran	GT_Index	TFP_OLS	TFP_FE	TFP_GMM	CEI
EGC	0.020 *** (0.002)	0.082 *** (0.002)	0.013 *** (0.002)	0.014 *** (0.002)	0.007 *** (0.001)	−0.022 *** (0.008)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	49,101	49,101	44,844	44,844	44,844	32,493
Adj_R ²	0.155	0.368	0.352	0.365	0.172	0.005

Note: Standard errors clustered in firm level are in parentheses; *** indicate significant at the 1% levels, respectively.

Jointly considered with the baseline results, which show positive effects on innovation and TFP, these findings indicate that Executive Green Cognition drives a decoupling of economic efficiency from carbon emissions. Specifically, EGC enhances production efficiency while simultaneously mitigating environmental intensity. This evidence provides micro-level support for the Porter Hypothesis and precludes the alternative explanation that productivity gains are driven by pollution-intensive scale expansion. Overall, these results corroborate that our core conclusion regarding the facilitating role of executive green cognition is robust to alternative measurement specifications.

4.3.2. Controlling Industry-Year Fixed Effects

To account for time-varying industry-specific shocks, we augment the baseline specification with Industry × Year fixed effects. This specification effectively absorbs unobserved heterogeneity arising from dynamic sector-specific factors, such as the implementation of environmental regulations or technological mandates in a given year. By capturing these confounding factors, we ensure that our estimates are not driven by external macro-level shocks.

Table 9 reports the re-estimation results incorporating these high-dimensional fixed effects. The analysis reveals that the coefficient on EGC remains positive and statistically significant at the 1% level for all outcome variables. Specifically, the coefficient for G_Innov is 0.033, while the coefficients for Total Factor Productivity (TFP_LP and TFP_OP) are both 0.007. The persistence of these positive effects, even after controlling for granular industry-time trends, robustly validates our core conclusion.

Table 9. Robustness check 3: Controlling Industry-Year Fixed Effects.

Variables	(1)	(2)	(3)
	G_Innov	TFP_LP	TFP_OP
EGC	0.033 *** (0.003)	0.007 *** (0.002)	0.007 *** (0.002)
Controls	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	49,101	49,101	49,101
Adj_R ²	0.361	0.454	0.454

Note: Standard errors clustered in firm level are in parentheses; *** indicate significant at the 1% levels, respectively.

4.3.3. Lagged Independent Variables

To mitigate concerns regarding reverse causality and to examine the temporal dynamics of the effect, we re-estimate the baseline specification using independent variables lagged by one (Lag1_EGC) and two (Lag2_EGC) periods. Table 10 reports the results.

Table 10. Robustness check 4: Lagged Independent Variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	G_Innov	TFP_LP	TFP_OP	G_Innov	TFP_LP	TFP_OP
Lag1_EGC	0.013 *** (0.002)	0.003 ** (0.001)	0.004 *** (0.001)			
Lag2_EGC				0.012 *** (0.000)	0.003 *** (0.007)	0.005 *** (0.001)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	43,509	43,509	43,509	38,030	38,030	38,030
Adj_R ²	0.177	0.274	0.308	0.164	0.267	0.295

Note: Standard errors clustered in firm level are in parentheses; **, and *** indicate significant at the 5%, and 1% levels, respectively.

Columns (1)–(3) present the estimates for the one-period lag. The results show that lagged EGC remains a statistically significant predictor of both Green Innovation (G_Innov, $\beta = 0.013$) and Total Factor Productivity (TFP_LP = 0.003; TFP_OP = 0.004). This positive relationship persists in the two-period lag specifications shown in Columns (4)–(6), where the coefficients for green innovation and productivity measures remain statistically significant at the 1% level.

The robustness of these estimates across lagged specifications establishes temporal precedence, indicating that current executive cognition predicts future organizational outcomes. This finding helps mitigate simultaneity bias and reinforces the causal interpretation of our baseline results.

4.3.4. Excluding Other Environmental Policies

To ensure that our baseline estimates capture the effect of executive cognition rather than concurrent policy shocks, we perform sensitivity analyses by excluding observations subject to major overlapping environmental regulations.

We first address the Air Pollution Prevention and Control Action Plan (APPCAP). We exclude firms located in the 57 designated Key Control Cities, which faced stringent emission targets. As reported in Table 11 (Panel A, Columns 1–3), the coefficient on EGC remains significantly positive, indicating that the results are not driven by this command-and-control regulation.

Table 11. Robustness check 5: Excluding other environmental policies.

Panel A	Air Pollution Prevention and Control Action Plan			Carbon Emissions Trading Pilots		
Variables	(1)	(2)	(3)	(4)	(5)	(6)
	G_Innov	TFP_LP	TFP_OP	G_Innov	TFP_LP	TFP_OP
EGC	0.012 *** (0.000)	0.007 *** (0.001)	0.003 * (0.065)	0.013 *** (0.000)	0.003 ** (0.022)	0.005 *** (0.001)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	22,764	21,076	22,764	30,138	30,138	30,138
Adj_R ²	0.184	0.389	0.285	0.197	0.274	0.295
Panel B	Measures for Interviews of the Ministry of Ecology and Environment			Environmental Protection Tax Law of China		
Variables	(1)	(2)	(3)	(4)	(5)	(6)
	G_Innov	TFP_LP	TFP_OP	G_Innov	TFP_LP	TFP_OP
EGC	0.013 *** (0.000)	0.003 ** (0.022)	0.013 *** (0.001)	0.011 *** (0.000)	0.004 ** (0.021)	0.006 *** (0.002)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	42,967	42,967	42,967	29,123	29,123	29,123
Adj_R ²	0.192	0.251	0.278	0.189	0.239	0.277

Note: Standard errors clustered in firm level are in parentheses; *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

Next, to account for market-based incentives, we remove firms located in the Carbon Emission Trading Pilot regions (e.g., Beijing, Shanghai, Guangdong). The estimates in Panel A (Columns 4–6) remain robust, suggesting our conclusion is independent of carbon market mechanisms.

Third, we control for the administrative pressure from the Central Environmental Protection Inspection (CEPI). We exclude observations from the 73 cities subject to direct regulatory interviews. The results in Panel B (Columns 1–3) confirm that the exogenous shock of inspections does not alter our findings.

Finally, regarding the 2018 Environmental Protection Tax Law, we exclude firms in the 12 provinces that raised tax rates during the transition from pollution discharge fees to environmental taxes. As shown in Panel B (Columns 4–6), the coefficient on EGC remains positive and significant.

Collectively, these subsample analyses verify that the facilitating role of executive green cognition is robust to the confounding effects of major regulatory reforms.

5. Further Analysis

5.1. Mechanisms Exploration

This section investigates the underlying mechanisms through which executive green cognition facilitates corporate green transformation. We hypothesize that this effect operates through three distinct channels: (1) mitigating green agency costs; (2) enhancing the quality of green information disclosure; and (3) expanding green investment. Following the causal mediation framework proposed by Jiang (2022), we employ the following regression model to empirically test these pathways [78]:

$$\text{Mechanism}_{it} = \alpha_0 + \alpha_1 \text{EGC}_{it} + \beta X_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (2)$$

where Mechanism represents the vector of mediator variables corresponding to the three hypothesized channels:

- (1) Green Agency Cost (GAC): Operationalized as the ratio of environmental governance expenses to total operating revenue. A higher ratio indicates greater severity of green agency costs. This indicator is computed by manually compiling environmental maintenance expenditures, including greening and sanitation fees, extracted from the Administrative Expenses line item in the income statements.
- (2) Environmental Information Disclosure Quality (EIDQ): Constructed as the natural logarithm of the aggregated scores for environmental disclosure items (detailed construction procedures are provided in Supplementary Material S3), following the content analysis framework established by Wiseman (1982) [79].
- (3) Green Investment (EPIInvest): Defined as annual environmental protection expenditure scaled by total assets at year-end. This variable aggregates capital expenditures explicitly related to environmental protection, including sewage treatment, desulfurization, waste gas abatement, denitrification, dust removal, and energy conservation, derived from the Construction in Progress notes in annual reports.

All other model specifications remain consistent with the baseline analysis.

5.1.1. Mitigating Green Agency Costs

Green agency costs primarily manifest as inefficient resource allocation where management prioritizes short-term interests over long-term environmental value. Common manifestations include excessive discretionary spending and the misappropriation of environmental funds for rent-seeking purposes. We posit that enhanced executive green cognition acts as a governance mechanism that curtails such agency behaviors. By internalizing efficiency norms, high-EGC executives restrict rent-seeking incentives and eliminate redundant expenditures, thereby mitigating green agency costs. Specifically, administrative expenses classified as greening and sanitation fees often function as non-productive consumption intended for image maintenance or basic end-of-pipe treatment rather than substantive process innovation. In the absence of a genuine strategic commitment, management may leverage these conspicuous expenditures to appease external stakeholders, a practice consistent with the theoretical definition of defensive spending in the agency cost literature.

Column (1) of Table 12 reports results where Green Agency Cost (GAC) serves as the dependent variable. The coefficient on EGC is -0.004 ($p < 0.01$), supporting Hypothesis 2. Furthermore, mediation validity is further rigorously tested using the Bootstrap method with 5000 resamples. As shown in Table 12, the 95% bias-corrected confidence intervals (CI) for the indirect effects do not contain zero, confirming that the mediation effect of green agency costs is statistically significant and robust.

Table 12. Mechanism Test Results.

Panel A Mechanism Effect Tests			
Variables	(1) GAC	(2) EIDQ	(3) EPInvest
EGC	−0.004 *** (0.002)	0.263 *** (0.017)	0.032 *** (0.008)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	49,101	49,101	47,688
Adj_R ²	0.006	0.393	0.015
Panel B Mediation Effect Tests Based on Bootstrapping			
Pathways	Indirect Effect	95% Conf. Interval	
EGC-GAC-G_Innov	0.0000883 **	[0.0000196, 0.0001572]	
EGC-GAC-TFP_OP	0.0002147 ***	[0.0001203, 0.0003093]	
EGC-GAC-TFP_LP	0.0002246 ***	[0.0000907, 0.0003586]	
EGC-EIDQ-G_Innov	0.0005912 ***	[0.0002711, 0.0009107]	
EGC-EIDQ-TFP_OP	0.0003057 ***	[0.0001429, 0.0004686]	
EGC-EIDQ-TFP_LP	0.0005688 ***	[0.0003794, 0.0007586]	
EGC-EPInvest-G_Innov	0.0001843 ***	[0.0000777, 0.0002908]	
EGC-EPInvest-TFP_OP	0.0000113 **	[0.0000026, 0.0000486]	
EGC-EPInvest-TFP_LP	0.0000113 **	[0.0000039, 0.0000616]	

Note: Standard errors clustered in firm level are in parentheses; ** and *** indicate the significance at the 5% and 1% levels, respectively.

These findings are critical for distinguishing substantive cognition from symbolic rhetoric. If the EGC measure merely captured greenwashing behaviors aimed at regulatory appeasement, one would anticipate a positive correlation between EGC and green agency costs, as firms typically incur non-productive expenditures, such as superficial landscaping, to signal legitimacy. However, the significant negative coefficient observed in Table 12 contradicts this prediction. Instead, the reduction in agency costs indicates that EGC functions as a substantive governance constraint that curbs managerial opportunism rather than serving as a tool for strategic impression management.

5.1.2. Enhancing Green Information Disclosure Quality

Information asymmetry between firms and stakeholders impedes the efficient allocation of resources. Transparent disclosure functions as the primary mechanism to mitigate this asymmetry. We posit that executives with heightened green cognition are more adept at recognizing the signaling utility of disclosure. Consequently, they proactively enhance the completeness and materiality of reports, specifically by increasing the provision of quantitative data and refining strategic planning details.

Column (2) presents the results where Environmental Information Disclosure Quality (EIDQ) is the dependent variable. The regression yields a significant positive coefficient for *EGC* ($\beta = 0.263$, $p < 0.01$). This finding is consistent with theoretical expectations and supports Hypothesis 3. Furthermore, the mediation validity is further rigorously tested using the Bootstrap method with 5000 resamples. As shown in Table 12, the 95% bias-corrected confidence intervals (CIs) for the indirect effects do not contain zero, confirming that the mediation effect of green information disclosure quality is statistically significant and robust.

5.1.3. Expanding Green Investment

Green investment constitutes a critical pathway for developing organizational environmental capabilities. The cognitive orientation of senior executives shapes the strategic direction of resource deployment. We posit that high levels of green cognition facilitate a more accurate assessment of the strategic value of environmental initiatives. Consequently, this cognitive shift prompts greater investment in specific projects, such as R&D and process innovation, thereby scaling up the firm's green asset base.

In Column (3), we employ Green Investment (*EPInvest*) as the outcome variable. The analysis yields a significant coefficient of 0.032 ($p < 0.01$) for EGC, supporting Hypothesis 4. The mediation validity is further rigorously tested using the Bootstrap method with 5000 resamples. As shown in Table 12, the 95% bias-corrected confidence intervals (CIs) for the indirect effects do not contain zero, confirming that the mediation effect of green investment is statistically significant and robust.

5.1.4. Analysis of Serial Mediation

To empirically test the hypothesized causal ordering, we employed a stepwise regression framework.

Table 13 presents the results of this serial analysis. The results in Column (1) indicate that Green Agency Costs (GAC) exhibit a significant negative association with Disclosure Quality (EIDQ) (Coefficient = -0.167 , $p < 0.10$). Since GAC proxies for managerial opportunism and non-productive expenditures, this negative relationship suggests that mitigating agency problems is a precondition for enhancing the credibility and quality of environmental reporting. In other words, effective internal governance serves as the foundation for transparent disclosure. Furthermore, Column (2) reveals that EIDQ exerts a significant positive impact on Green Investment (*EPInvest*) (Coefficient = 0.050 , $p < 0.01$).

Table 13. Stepwise Regression Results of Mechanism Interdependencies.

Variables	(1)	(2)	(3)	(4)	(5)
	EIDQ	EPInvest	G_Innov	TFP_OP	TFP_LP
EGC	0.262 *** (0.017)	0.019 ** (0.008)	0.002 * (0.001)	0.012 *** (0.002)	0.004 *** (0.001)
EPInvest			0.002 * (0.001)	0.005 *** (0.002)	0.002 * (0.001)
EIDQ		0.050 *** (0.005)	0.001 *** (0.000)	0.002 ** (0.001)	0.002 *** (0.000)
GAC	-0.167 * (0.091)		-0.053 *** (0.007)	-0.023 ** (0.010)	-0.055 *** (0.008)
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	43,509	43,509	38,030	43,509	38,030
Adj_R ²	0.177	0.274	0.308	0.164	0.267

Note: Standard errors clustered in firm level are in parentheses; *, ** and *** indicate the significance at the 10%, 5% and 1% levels, respectively.

This finding aligns with the signaling hypothesis, which posits that high-quality disclosure reduces information asymmetry and alleviates external financing constraints. Consequently, improved transparency facilitates the capital accumulation necessary for substantive green projects. Collectively, these estimates corroborate the sequential logic

that governance improvements foster transparency, which subsequently drives substantive investment.

Furthermore, we employed standardized regression estimates to identify the primary drivers of green transformation. As shown in Appendix A Table A3, Green Investment and Green Agency Costs exhibit the strongest associations with productivity outcomes. The standardized effect size of Disclosure Quality is significantly smaller, roughly half that of the substantive mechanisms. This comparison reveals that while disclosure acts as a requisite facilitating channel, the transformation process is primarily propelled by substantive resource commitment and governance constraints driven by executive cognition.

5.2. Moderating Effect of Digital Transformation

Digital transformation empowers firms to enhance their capacity for collecting, analyzing, and integrating environmental data. This enables executives to precisely identify green technology opportunities and risks, thereby efficiently translating green cognition into strategic decisions. Furthermore, digital-driven collaboration and intelligent production processes reduce the trial-and-error costs of green investment, accelerating the conversion of cognition into actual investment and optimizing resource allocation. Finally, digital platforms allow for real-time monitoring of innovation dynamics, providing continuous feedback that facilitates the iterative optimization of green decisions and amplifies the long-term impact of green cognition.

To empirically examine this moderating role, we specify the following model augmented with an interaction term:

$$GT_{it} = \alpha_0 + \alpha_1 EGC_{it} \times Digital_{it} + \alpha_2 EGC_{it} + \alpha_3 Digital_{it} + \beta X_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (3)$$

where $Digital_{it}$ denotes the degree of corporate digital transformation; all other variables follow the baseline specification. Following Wu et al. (2021) and Chen et al. (2019), we measure this variable by aggregating the frequency of digital transformation-related keywords in annual reports and taking the natural logarithm of the total frequency plus one (in the Supplementary Material S4 and S5, we have explicitly elaborated on the data processing methodology, the rationale for keyword selection, and illustrative cases of digital technology applications) [80,81]. To further rule out the possibility that the interaction term captures general management efficiency, we controlled for Total Asset Turnover (ATO) and the Management Expense Ratio (Mfee).

Table 14 reports the regression results for the moderating effect of digital transformation. The coefficient on the interaction term ($EGC \times Digital$) is positive and statistically significant at the 1% level for Green Innovation (G_Innov), as well as for Total Factor Productivity measures (TFP_LP and TFP_OP).

Table 14. Estimation Results of the Moderating Effect of Digital Transformation.

Variables	(1)	(2)	(3)
	G_Innov	TFP_LP	TFP_OP
EGC × Digital	0.005 *** (0.001)	0.001 ** (0.001)	0.001 ** (0.001)
EGC	0.006 ** (0.003)	0.004 *** (0.001)	0.006 *** (0.001)
Digital	0.054 *** (0.008)	0.043 *** (0.005)	0.062 *** (0.005)
ATO	−0.028 (0.028)	0.769 *** (0.019)	0.822 *** (0.021)
Mfee	−0.616 ***	−3.054 ***	−3.454 ***

	(0.106)	(0.091)	(0.102)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	49,052	49,052	49,052
Adj_R ²	0.196	0.257	0.291

Note: Standard errors clustered in firm level are in parentheses; ** and *** indicate the significance at the 5% and 1% levels, respectively.

Crucially, the model controls for the direct effect of digital transformation (α_3), which captures the baseline productivity gains associated with digitalization. Consequently, the significance of the interaction term identifies the complementarity between executive cognition and digital infrastructure. This result implies that digital capabilities reduce the friction in implementing environmental strategies, thereby enhancing the elasticity of green transformation with respect to executive cognition. This specification effectively rules out the alternative explanation that the observed gains are driven solely by the independent impact of digitalization. These findings support Hypothesis 5.

5.3. Heterogeneity Analysis

We posit that the strategic importance of executive green cognition is contingent upon the severity of external pressures. Although regulatory and ownership mandates necessitate compliance, they often engender organizational inertia and high adjustment costs. In these constrained settings, EGC functions as a pivotal driver in overcoming internal rigidity, allowing for the effective redirection of resources toward substantive transformation. We investigate this variation by analyzing effect heterogeneity across diverse property rights regimes, industry characteristics, and urban institutional environments.

5.3.1. Property Rights

Given distinct institutional mandates and resource endowments, we stratify the sample by ownership type to examine potential heterogeneity. We introduce a dummy variable, SOE, equal to 1 for state-owned enterprises and 0 otherwise. As reported in Table 15, while the coefficient of EGC is statistically significant at the 1% level for both subsamples, the economic magnitude is substantially larger for SOEs. This difference suggests that state ownership amplifies the promoting effect of executive green cognition.

Table 15. Heterogeneity estimation results 1: Property rights.

Variables	<i>G_Innov</i>		<i>TFP_LP</i>		<i>TFP_OP</i>	
	(1)	(2)	(3)	(4)	(5)	(6)
	SOE	NonSOE	SOE	NonSOE	SOE	NonSOE
EGC	0.021 *** (0.004)	0.019 *** (0.003)	0.010 *** (0.002)	0.010 *** (0.001)	0.013 *** (0.002)	0.012 *** (0.002)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	15,374	33,719	15,374	33,719	15,374	33,719
Adj_R ²	0.191	0.099	0.192	0.159	0.238	0.191

Note: Standard errors clustered in firm level are in parentheses; *** indicate the significance at the 1% levels, respectively.

We attribute this differential impact to three structural factors. First, SOEs operate under explicit political mandates for environmental governance. High executive green

cognition enables these firms to align strategic planning with national policy objectives, thereby securing political legitimacy and reducing the transaction costs associated with regulatory compliance. Second, regarding resource allocation, although SOEs benefit from preferential access to credit and land in factor markets, they are historically prone to agency inefficiencies and soft budget constraints. In this context, EGC serves as a corrective mechanism that redirects capital toward substantive green innovation, ensuring that superior resource endowments translate into technological upgrades rather than being dissipated through non-productive administrative consumption. Third, the objective function of SOEs incorporates social value and long-term sustainability, creating an incentive structure compatible with green transformation. EGC fosters congruence between executive values and these organizational mandates, thereby mitigating managerial myopia. Conversely, non-SOEs face intense market discipline focused on short-term profitability, which imposes high opportunity costs on long-term green investments and attenuates the translation of cognitive intent into action.

5.3.2. Urban Characteristics

To account for variations in regional industrial structure and environmental pressure, we introduce a binary variable, *CityType*, assigned a value of 1 for resource-based cities and 0 otherwise. Table 16 reports the subgroup estimation results. While EGC exerts a positive effect in both subsamples, the magnitude differs significantly. Specifically, the coefficient for Green Innovation (*G_Innov*) is substantially larger in resource-based cities, indicating a higher marginal contribution of executive cognition to transformation outcomes in these regions. Notably, the higher Adjusted R^2 in the resource-based group suggests that EGC possesses greater explanatory power regarding innovation variance in these settings.

Table 16. Heterogeneity estimation results 2: Urban Characteristics.

Variables	G_Innov		TFP_LP		TFP_OP	
	(1) Resource-Based	(2) Non-Resource-Based	(3) Resource-Based	(4) Non-Resource-Based	(5) Resource-Based	(6) Non-Resource-Based
EGC	0.027 *** (0.006)	0.022 *** (0.002)	0.010 *** (0.004)	0.011 *** (0.001)	0.011 *** (0.004)	0.013 *** (0.002)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	4285	44,816	4285	44,816	4285	44,816
Adj_ R^2	0.113	0.140	0.201	0.160	0.229	0.198

Note: Standard errors clustered in firm level are in parentheses; *** indicate the significance at the 1% levels, respectively.

We attribute this pronounced effect to the critical role of EGC in counteracting structural rigidities and industrial path dependence. Resource-based cities are characterized by high carbon lock-in and strict regulatory scrutiny, which necessitate a fundamental strategic transition. In such high-constraint environments, high EGC enables executives to interpret external pressures as imperatives for industrial upgrading rather than merely as compliance costs. Consequently, this cognitive orientation facilitates substantive process restructuring. Furthermore, executives with high green cognition are better positioned to align corporate strategy with regional policy incentives, thereby leveraging external resources to accelerate implementation. Conversely, firms in non-resource-based cities operate under weaker institutional constraints, where the translation of cognitive

intent into action is more likely to be diminished by short-term profitability considerations.

5.3.3. Industrial Attributes

Following the classification guidelines of the Ministry of Ecology and Environment, we stratify the sample into high-pollution (e.g., chemical, steel) and low-pollution (e.g., services) sectors. As reported in Table 17, the magnitude of the EGC coefficient is significantly larger in the high-pollution subsample.

Table 17. Heterogeneity estimation results 3: Industrial attributes.

Variables	G_Innov		TFP_LP		TFP_OP	
	(1) HeavyPoll	(2) Non- HeavyPoll	(3) HeavyPoll	(4) Non- HeavyPoll	(5) HeavyPoll	(6) Non- HeavyPoll
EGC	0.024 *** (0.003)	0.020 *** (0.003)	0.011 *** (0.002)	0.009 *** (0.002)	0.013 *** (0.002)	0.012 *** (0.002)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	15,389	33,712	15,389	33,712	15,389	33,712
Adj_R ²	0.116	0.114	0.190	0.150	0.221	0.187

Note: Standard errors clustered in firm level are in parentheses; *** indicate the significance at the 1% levels, respectively.

We attribute this heterogeneity to two economic mechanisms. First, regarding regulatory stringency, high-pollution sectors face stricter supervision, which elevates the shadow cost of non-compliance. In this context, executive green cognition is critical for internalizing environmental externalities and mitigating regulatory risks, thereby accelerating the translation of strategy into compliance actions. Conversely, the weaker institutional constraints in low-pollution sectors reduce the immediate economic incentives for such translation. Second, concerning asset characteristics, high-pollution firms typically possess extensive industrial assets suitable for retrofitting. EGC facilitates the efficient re-configuration of these legacy assets, effectively lowering the marginal cost of abatement. In contrast, low-pollution sectors often lack such complementary operational bases, resulting in higher marginal costs for implementing substantive green technologies.

6. Conclusions and Implications

To balance the objectives of economic growth and decarbonization, this study integrates Upper Echelons Theory and Agency Theory to investigate the micro-foundations of corporate green transition. Utilizing a panel dataset of Chinese listed firms from 2010 to 2024, we provide empirical evidence that executive green cognition (EGC) is a critical determinant prompting firms to shift from superficial compliance to substantive transformation. This study advances the theoretical literature in the following dimensions:

First, this study expands the micro-level explanatory framework within environmental economics. While the existing literature emphasizes external regulatory pressures, such as environmental taxes [4,5], or stakeholder constraints [28,29], we demonstrate that external pressure is a necessary but insufficient condition for transition. We identify EGC as the critical internal mechanism determining the depth of corporate restructuring. By linking this cognitive micro-foundation to firm behavior, we explain the heterogeneity in strategic responses among firms facing identical regulatory intensities [19], thereby extending Upper Echelons Theory to the domain of environmental governance.

Second, we provide micro-level evidence supporting the Porter Hypothesis and clarify the economic consequences of green transition [31]. Addressing the limitations of prior studies that rely on single-dimensional indicators, we employ a dual-dimensional assessment framework. The results confirm that firms with high EGC achieve simultaneous improvements in green innovation output and Total Factor Productivity (TFP). Furthermore, by documenting a significant decline in carbon emission intensity (CEI), we exclude the alternative explanation that productivity growth derives from scale expansion. This confirms that cognitively aligned executives generate innovation compensation effects, realizing a Pareto improvement in both environmental performance and economic competitiveness.

Third, we elucidate the resource allocation mechanism linking cognition to behavioral outcomes. We conceptualize EGC as an internal governance mechanism that internalizes environmental externalities. Managers with high green cognition effectively mitigate agency costs associated with managerial myopia. Our mechanism analysis indicates that EGC significantly reduces defensive expenditures while fostering substantive investments in R&D and equipment upgrades. This reallocation effect differentiates the pathways driving substantive decarbonization from those leading to mere compliance, offering a theoretical basis for stimulating endogenous corporate green transition.

Furthermore, we delineate the boundary conditions involving digital and institutional contexts. We find that digital transformation positively moderates the facilitative effect of EGC. This aligns with the recent literature on the dual digital and green transition [25], suggesting that digital infrastructure acts as an operational enabler that reduces the marginal cost of implementation. Additionally, the effect of EGC is amplified in state-owned enterprises, pollution-intensive industries, and resource-based cities. This indicates that cognition-driven transition exhibits stronger adaptability under conditions of stringent regulatory constraints and specific resource endowments.

These findings imply that firms should shift from relying solely on mandatory external regulation to cultivating endogenous corporate momentum. Policymakers should support executive education programs emphasizing the economic materiality of environmental risks, thereby shifting managerial mindsets from viewing environmental protection as a compliance burden to recognizing it as a strategic opportunity. To operationalize this cognitive shift, corporate boards should design compensation contracts that explicitly link managerial payoffs to long-term environmental metrics, such as carbon emission intensity and green patent quality, to correct intertemporal decision-making biases. Additionally, given the positive moderating role of digitalization, policy frameworks should encourage the convergence of digital and green transitions, particularly by subsidizing digital infrastructure in manufacturing to reduce information processing costs in environmental management.

We acknowledge two limitations that point toward future research directions. First, regarding measurement, we employ textual analysis of corporate annual reports. Although prioritizing the statutory Management Discussion and Analysis section and conducting validity tests mitigates the risk of symbolic compliance, text-based proxies inherently contain noise and may not perfectly capture executive psychological nuances. Future research could employ alternative methods, such as psychometric analysis of speech or experimental designs, to triangulate these measures. Second, regarding external validity, the sample is restricted to Chinese listed companies. While China provides a unique context for studying transition economies, the specific institutional environment may limit direct generalizability. However, the revealed mechanisms possess broader theoretical applicability; future research should test these mechanisms in diverse institutional contexts, such as developed economies, or extend the analysis to unlisted SMEs to further validate the cognitive foundations of corporate environmental behavior.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18042034/s1>. Supplementary Materials S1: Construction Method of the Variable Env_BG; Supplementary Materials S2: Construction Method of the Variable GW; Supplementary Materials S3: Construction Method of the Variable EIDQ; Supplementary Materials S4: Construction Method of the Variable Digital; Supplementary Materials S5: Illustrative Cases of Digital Transformation; Table SM1: Environmental Information Disclosure Index Scoring Standard; Table SM2: Keywords for Enterprises' Digital Transformation; Table SM3: Illustrative Cases of Digital Transformation.

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Appendix A

Appendix A.1

Table A1. Keywords of Executive Green Cognition.

Keywords of Executive Green Cognition
Environmental protection; Energy saving; Emission reduction; Environmental protection strategy; Environmental protection concept; Environmental management agency; Environmental education; Environmental training; Environmental technology development; Environmental auditing;; Environmental policy; Environmental department; Environmental inspector; Low carbon; Environmental protection efforts; Environmental governance; Environmental management; Environmental facilities; Environmental laws and regulations; Pollution control

Appendix A.2

Table A2. Validation Test.

Variables	(1)	(2)	(3)	(4)
	EGC	G_Innov	TFP_OP	TFP_LP
Env_BG	2.130 *** (0.319)			
EGC		0.011 *** (0.002)	0.003 * (0.001)	0.003 * (0.001)
GW		0.166 *** (0.016)	0.025 *** (0.008)	0.057 *** (0.009)
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	No	No	No
Firm FE	No	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	49,101	44,327	44,327	44,327
Adj_R ²	0.092	0.210	0.253	0.287

Note: Standard errors clustered in firm level are in parentheses; * and *** indicate the significance at the 10% and 1% levels, respectively.

Appendix A.3

Table A3. Standardized Estimation of Competitive Mechanisms.

Variables	(1)	(2)	(3)
	z_G_Innov	z_TFP_LP	z_TFP_OP
z_EGC	0.044 *** (0.008)	0.015 *** (0.005)	0.015 *** (0.005)
z_GAC	−0.015 ** (0.007)	−0.039 *** (0.006)	−0.039 *** (0.006)
z_EIDQ	0.015 ** (0.006)	0.019 *** (0.004)	0.019 *** (0.004)
z_EPInvest	0.016 *** (0.004)	0.041 *** (0.012)	0.041 *** (0.012)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	47,688	47,688	47,688
Adj_R ²	0.194	0.288	0.288

Note: Standard errors clustered in firm level are in parentheses; ** and *** indicate the significance at the 5% and 1% levels, respectively.

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