

Article

Can Sustainable Finance Policy Reduce Regional Green Innovation Disparities? A Strategic Innovation Perspective

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Abstract

Regions dominated by brown industries have long been excluded from conventional green financial systems, reinforcing spatial inequality in green innovation. Under financing constraints, brown firms tend to adopt strategic innovation behaviors—namely, symbolic, intermittent, or displaced innovation. These behaviors create technological lock-in and exacerbate regional disparities. Sustainable finance offers a potential pathway by targeting support to transformable brown firms. Using China's north–south green innovation divide as a case, we find that sustainable finance policy significantly narrows regional green innovation disparities. Mechanism analysis reveals that the policy differentially suppresses three strategic innovation archetypes. It attenuates symbolic and intermittent innovation through funding conditionality and inter-temporal incentives yet fails to curb displaced innovation where funds are diverted toward non-green projects. Furthermore, patient capital and ESG ratings can synergistically enhance the efficiency of sustainable finance policy. These conclusions offer valuable insights for the advancement of regional rebalancing in green innovation.

Keywords: sustainable finance policy; regional green innovation disparity; strategic innovation; patient capital; ESG rating

1. Introduction

Unbalanced regional development persists as a critical sustainability challenge globally. Advanced economies exhibit core–periphery divides, as evident in the U.S. Rust Belt versus coastal hubs and Italy's north–south divide [1,2], while developing nations face compounded disparities like India's urban–rural fragmentation and Brazil's coastal–hinterland polarization [3,4]. These inequalities fundamentally stem from asymmetric regional innovation ecosystems [5,6]. Meanwhile, the traditional green financial system exacerbates this through 'green marginalization'. Specifically, technologically advanced regions dominate emerging sustainable industries and are more favored by capital, whereas structurally constrained areas remain locked in obsolete paradigms [7]. This divergence institutionalizes new forms of spatial inequality through technological exclusion, demanding urgent policy mechanisms to reconfigure innovation capital and break path-dependent trajectories [8].

Regions dominated by brown industries face three structural barriers: physical-capital specificity, human-capital inertia, and institutional stickiness. These barriers make it challenging for such regions to bridge the innovation gap with areas that have well-developed



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green industries [9]. More critically, the prevailing green financial system exhibits bias toward commercially mature low-carbon technologies, systematically excluding brown industrial zones from green innovation networks [10,11]. Sustainable finance policies provide feasible pathways through institutional redesign [12]. Specifically, the development of a 'brown-to-green' mechanism presents an opportunity for regions with limited green innovation capacity to overcome the lock-in effect and ultimately bridge the regional disparities in green innovation.

The challenge in narrowing regional green innovation disparity stems fundamentally from the strategic innovation behaviors adopted by brown firms. However, we argue that strategic innovation is not a monolithic phenomenon but encompasses three distinct archetypes, each contributing to regional disparities through different mechanisms and therefore requiring differentiated policy responses. Brown firms under financing constraints exhibit heightened susceptibility to short-term incentives, amplifying their tendency toward all three forms of strategic innovation.

The first archetype, symbolic innovation, occurs when firms engage in patent applications or disclosure activities without commensurate R&D investment, generating a proliferation of low-quality patents that contribute no genuine knowledge accumulation [13]. The second, intermittent innovation, is characterized by sharp volatility in R&D expenditure as firms opportunistically time their investment to coincide with policy evaluation windows, scaling up to secure financing and subsequently retrenching once funding is obtained [14,15]. The third, displaced innovation, occurs when firms channel transition funds toward low-risk, non-green projects that satisfy compliance requirements but fail to advance the green technological frontier [16,17]. Meanwhile, sustainable finance policies, by alleviating investment cashflow sensitivity, have the potential to discipline each archetype through differentiated mechanisms, tightening conditionality for symbolic innovation, imposing inter-temporal penalties for intermittent innovation, and mandating fund-use transparency requirements.

Notably, these three archetypes are not mutually exclusive; a single firm may exhibit multiple forms simultaneously or sequentially. This recognition of potential hybridization and temporal substitution across strategic innovation archetypes carries important implications for both theory and policy. If firms can simultaneously combine multiple forms of opportunism or sequentially switch between archetypes as policy constraints evolve, static category-based analyses may understate firms' adaptive capacity and overstate the effectiveness of single policy interventions [12]. For instance, a firm may initially pursue symbolic innovation to secure financing, then transition toward displaced innovation by exploiting the opacity of fund allocation [18]. This dynamic adaptability implies that effective policy design must adopt a dynamic, multi-layered monitoring approach that tracks not only patent quality and R&D volatility but also the ultimate deployment of funds, thereby closing the loopholes that enable firms to shift across forms of strategic opportunism [19].

Although sustainable finance policies possess the potential to hinder the strategic innovation behaviors of brown firms, their effectiveness depends on both internal and external conditions surrounding the firm. Internally, patient capital aligns investment incentives with long-term environmental goals by mitigating principal-agent conflicts, thereby inhibiting strategic innovation behaviors [20]. Externally, ESG ratings establish market-based reputational constraints through mandatory disclosure and analyst scrutiny, elevating implicit costs of strategic innovation [21]. Crucially, the interplay between internal investment incentives and external reputational constraints may create governance multiplier effects that amplify the impact of sustainable finance policies. Therefore, green innovation laggards often lack sufficient patient capital and have underdeveloped ESG

rating systems [22,23]. A strategic policy mix is urgently needed to enhance the regional institutional environment and address the spatial divergence inherent in green innovation.

At present, China's shift toward an innovation-driven economy faces constraints arising from the north–south green innovation divide. Figure 1 shows that northern China has consistently underperformed southern China in green innovation. Moreover, Figure 2 indicates that brown industrial agglomeration and regional green innovation are strongly negatively correlated. Brown industrial agglomeration is calculated based on industrial main business income and the location entropy approach for China's provinces from 2012 to 2023. Therefore, promoting the transformation of brown firms has become a critical pathway to enhance national innovative capacity, especially in the northern region, where brown industries dominate.

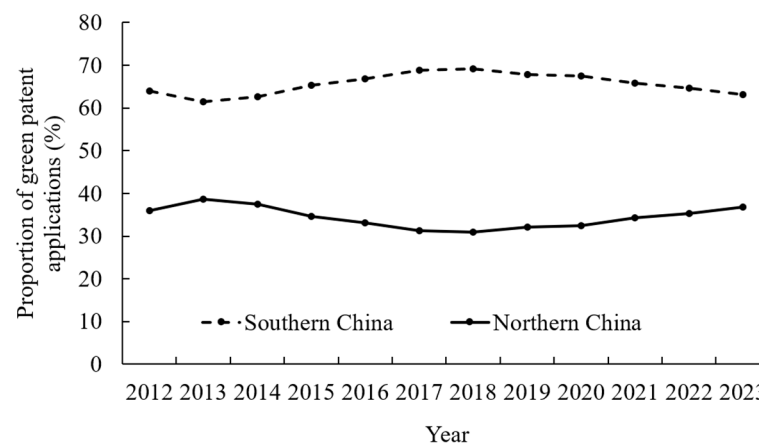


Figure 1. The proportion of green patent applications in northern and southern China.

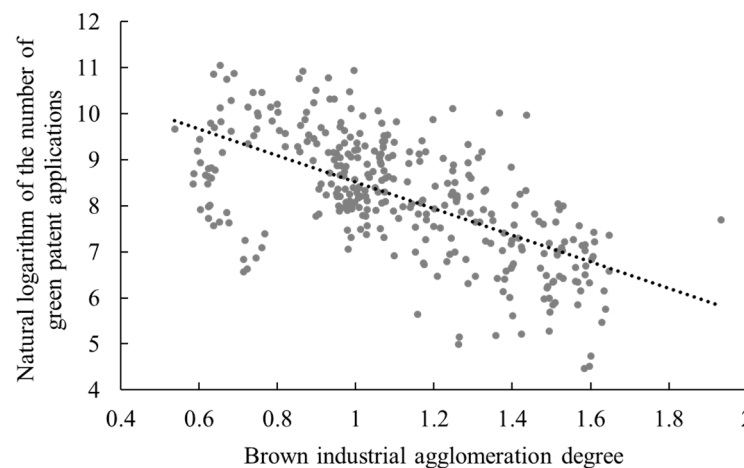


Figure 2. Association between brown industrial agglomeration and green innovation.

A strategic response from Chinese policymakers has been the implementation of sustainable finance instruments. Prominent among these is the China Green Bond Endorsed Project Catalogue, which was endorsed by the People's Bank of China in December 2015. The policy establishes sector-specific financing channels for six brown industries to support their green innovation (<https://docs.static.szse.cn/www/lawrules/rule/allrules/bussiness/W020190425335217707322.pdf>, (accessed on 1 July 2026)). Therefore, this study explores the mechanism by which sustainable finance policy narrows green innovation disparities across regions. Specifically, we ask the following: (1) Can sustainable finance policy reduce regional green innovation disparities? (2) Does it operate by suppressing strategic innovation, and do its effects differ across the three archetypes—symbolic, inter-

mittent, and displaced? (3) Do patient capital and ESG ratings synergistically enhance this gap-narrowing effect? The potential dynamic interactions among these strategic innovation archetypes, while theoretically important, cannot be fully addressed within our current empirical design. Nevertheless, we return to their implications in the Discussion and call for future longitudinal research to trace how firms re-optimize their strategic innovation portfolios over time. Our findings offer a theoretical framework for emerging economies to address spatial imbalances in green governance processes and provide actionable insights to facilitate the transformation of brown firms.

This study contributes to the literature in three ways. First, this article directly examines the causal relationship between sustainable financial policies and regional green innovation disparities. Despite extensive research on how green finance drives green innovation [16,24,25], the persistent spatial imbalance in green innovation of emerging economies remains understudied. This study pioneers an examination of whether and how sustainable finance policies narrow regional green innovation disparities, thereby uncovering the spatial mechanisms through which financial instruments reallocate innovation capital. Our findings address a critical theoretical lacuna governing geographical divergence within green innovation ecosystems.

Second, this study advances the behavioral theory of the firm by disaggregating the monolithic concept of strategic innovation into three theoretically and empirically distinct archetypes: symbolic, intermittent, and displaced. Existing studies have extensively documented the adverse economic impacts of enterprises' strategic innovation behaviors [26–28], largely treating such behavior as a uniform phenomenon, obscuring the differential mechanisms through which various forms of opportunism impede genuine technological progress. By demonstrating that sustainable finance policies exert heterogeneous inhibitory effects across these archetypes, we offer a refined understanding of how financial conditionality and inter-temporal incentive structures reshape corporate R&D trajectories. This typology-based analysis enriches the sustainable finance literature by revealing that the suppression of strategic innovation is not a binary outcome but a nuanced process requiring differentiated policy calibration.

Third, our moderation analysis reveals that the effectiveness of sustainable finance is amplified by patient capital and ESG ratings that we conceptualize as a multi-layered governance system. Previous studies on regional divides have tended to examine financial instruments or policy incentives in isolation [2,4,12] while largely overlooking the role of the local institutional environment. Building on our assessment of the effectiveness of financial instruments, this paper develops a collaborative framework that integrates internal and external governance conditions, through which we analyze the effect of patient capital and ESG ratings. This study provides a theoretical basis for regions lagging in green innovation to avoid implementing 'one-size-fits-all' sustainable finance policies.

The rest of this paper is divided into four sections. Section 2 reviews the literature and develops hypotheses. Section 3 details our empirical strategy. Section 4 reports the results. Section 5 concludes this paper, including a discussion of implications and limitations.

2. Literature Review and Hypothesis Development

2.1. Literature Review

2.1.1. Determinants of Green Innovation

Three factors are commonly identified as drivers of green innovation: environmental regulation, market forces, and organizational capabilities. Taking regulation first, the Porter Hypothesis argues for its catalytic role, but a counterview warns that overly rigid policies may discourage experimentation [29,30]. Market dynamics also matter, as eco-conscious consumer demand and ESG-linked investment flows shape green innovation

patterns across industries [25,31]. Finally, organizational capabilities, including knowledge absorption, dynamic resource reconfiguration, and entrepreneurship, influence how firms turn external pressures into actual green innovations [32,33].

Moreover, financial mechanisms are increasingly recognized as vital enablers of green innovation. Sustainable finance directs capital towards low-carbon technologies through instruments such as green bonds, ESG-linked loans, and sustainability-linked financial products [34,35]. A growing strand of literature has examined how sustainable finance instruments reshape corporate innovation behavior [36], yet the spatial implications of such financial reallocation, particularly whether sustainable finance can redress rather than reinforce regional inequalities, remain insufficiently explored. This gap hinders the design of spatially targeted policies aimed at bridging the green innovation disparity.

Beyond these firm-level drivers, a parallel strand of literature emphasizes the role of regional contextual factors in shaping green innovation trajectories. Studies have documented that local governance quality, including government effectiveness, regulatory enforcement, and institutional transparency, significantly influences the implementation and efficacy of environmental policies across regions [6,30]. Educational infrastructure, measured by the density of research universities and technical training institutions, determines the local talent pool and absorptive capacity for external knowledge [5,32]. Technological spillovers, transmitted through inter-regional patent citation networks or labor mobility, facilitate the diffusion of green knowledge from frontier regions to lagging areas [7]. Regional policy heterogeneity, such as differentiated environmental targets or innovation subsidy schemes across provinces, further creates uneven playing fields that affect firms' innovation incentives [29]. While these macro-level factors undoubtedly contribute to regional innovation disparities, our study focuses specifically on the financial mechanism through which sustainable finance policy addresses the strategic innovation behaviors of brown firms.

2.1.2. Economic Consequences of Sustainable Finance

Sustainable finance reallocates capital and transforms industrial structures to drive macroeconomic progress toward net-zero goals. By channeling investments into the replacement of brown industries [11], it hastens the shift away from traditional economic models and fosters regional economic sustainability [37]. Meanwhile, the effectiveness of sustainable finance depends on strict process compliance by banks and other financiers and the stringency of oversight [38]. However, sustainable finance must strike a balance between cost-effectiveness and economic inclusiveness to mitigate the risks of regional economic contraction that may arise from industrial transformation [39].

Moreover, sustainable finance influences corporate investment decisions by linking capital cost with emission reduction performance. It is reflected in inhibition of the short-term opportunistic behaviors exhibited by brown firms while directing resource allocation towards long-term technological advancements [16]. To some extent, sustainable finance can curb the opportunistic R&D practices of brown firms, particularly in detecting and penalizing greenwashing [11,35]. Nevertheless, existing studies have largely treated strategic innovation as a homogeneous phenomenon, overlooking the possibility that different types of opportunistic behavior may respond differently to financial incentives. Furthermore, the spatial rebalancing mechanisms associated with sustainable finance—specifically, whether and how it addresses the center–periphery dilemma inherent in green innovation—remain critically under-theorized and empirically untested.

2.1.3. The Incentives and Disincentives for Strategic Innovation

The motivation for enterprises to pursue strategic innovation is primarily driven by short-term interests and institutional pressures. On one hand, market competition compels

enterprises to prioritize immediate financial returns and capture market share through low-cost, low-risk strategic innovations instead of investing in long-term, high-risk disruptive innovations [40]. Conversely, when facing compliance pressures, such as environmental policies or industry standards, firms may resort to strategic innovation as a quick way to meet those requirements [12]. Furthermore, such strategic behavior can entrench a short-term focus within companies and create a risk of technological lock-in [41].

To curb strategic innovation effectively, firms must optimize internal governance and strengthen external institutional constraints. Internally, changes to executive leadership, organizational design, and competitive positioning can help firms better reconcile short-term gains with long-term knowledge building [42]. Externally, ESG rating systems have increasingly served as a valuable supplement to regulatory oversight, using market forces to penalize greenwashing [25,43]. Despite extensive documentation of strategic innovation's adverse consequences, existing literature has largely treated it as a monolithic construct, overlooking the potential heterogeneity in its manifestations and the possibility that different forms of opportunistic behavior may respond differently to financial incentives. Similarly, prior research has largely examined internal and external governance factors in isolation, neglecting their interplay with the financial system and their potentially heterogeneous effects across different strategic innovation archetypes.

2.2. Hypotheses Formulation

2.2.1. The Gap-Narrowing Effect of Sustainable Finance Policies

Regional disparities in green innovation primarily stem from structural industrial compositions. Areas dominated by brown industries face exclusion from conventional green finance systems, which typically prioritize low-carbon sectors [11]. This structural bias reinforces path dependence, as regions reliant on brown industries lack access to capital for technological upgrading [40]. Over time, such regions develop institutional and technological lock-ins that perpetuate underinvestment in green innovation. Therefore, the lack of effective financial instruments exacerbates the misallocation of innovation resources, creating a self-reinforcing cycle in which regions dominated by brown industries lack support for green innovation and become increasingly dependent on brown industries [44].

Sustainable finance policy addresses the limitations of traditional green finance by directing capital to green innovation. It does so by relaxing the financing constraints of brown firms that have viable transformation potential, thereby directly supporting these enterprises [45]. This policy not only dismantles the self-reinforcing mechanism associated with high-carbon technology path dependence of regions lagging in green innovation but also reconstructs the inter-regional knowledge spillover network [46]. Consequently, the reallocation of financial resources empowers marginal regions to overcome constraints stemming from institutional exclusion and inadequate technological absorptive capacity, thereby gradually narrowing the regional disparity in green innovation.

Accordingly, we posit the following hypothesis:

Hypothesis 1. *Sustainable finance policy is conducive to narrowing regional green innovation disparities.*

2.2.2. The Mechanism Effect of Strategic Innovation

The tendency of brown firms in backward regions to pursue strategic innovation contributes significantly to the ever-growing disparities in green innovation across regions [21]. However, we argue that this tendency manifests through three distinct archetypes—symbolic, intermittent, and displaced—each contributing to regional disparities through different pathways. Symbolic innovation drains resources without generating any knowledge capital, creating a hollow innovation ecosystem that inflates patent statistics without

substantive progress [26,28]. Intermittent innovation prevents the accumulation of persistent knowledge capital through volatile R&D cycles, resulting in a stop–start trajectory that never reaches critical mass for breakthrough innovation [15,47]. Displaced innovation diverts funds toward non-green projects, creating opportunity costs that slow the technological catch-up process in lagging regions [12,48]. Collectively, these three archetypes form a low-level equilibrium trap that perpetuates the innovation gap between brown-dominated and green-leading regions.

Limited by capital and technology accumulation, enterprises in lagging regions are more inclined to adopt these low-cost and low-risk strategic innovation practices to cope with short-term policy compliance pressure or obtain subsidies. This focus on strategic innovation, regardless of its specific archetype, diverts resources away from substantive innovation, resulting in a low-level equilibrium in regional innovation capabilities [47]. In contrast, green innovation leaders tend to secure conventional sustainable finance more easily due to their technological edge, thereby reinforcing the ‘rich-get-richer’ dynamic and worsening the spatial imbalance in green innovation [49].

Sustainable finance policies inhibit the strategic innovation of brown firms through differentiated mechanisms tailored to each archetype. First, they establish a threshold for fund applications. The dynamic connection between financing eligibility and firms’ emission reduction performance over their life cycle pushes brown firms to abandon symbolic innovation and instead commit to enduring R&D efforts that yield genuine technological progress [48]. Second, inter-temporal reward and punishment rules are constructed. Financial penalties are imposed on firms that fail to achieve technological upgrading goals, thereby increasing the opportunity cost of intermittent innovation and smoothing R&D volatility [50]. Third, use-of-proceeds transparency requirements and project-level auditing mechanisms are implemented, raising the detection risk and reputational costs of displaced innovation [12]. This triple constraint and forcing mechanism weaken the path dependence of brown firms on all three forms of strategic innovation and gradually break the vicious cycle of ‘strategic innovation–resource misallocation–regional disparity’.

However, the inhibitory effects of sustainable finance policy on these three strategic innovation archetypes are unlikely to be uniform, as they critically depend on the verifiability of each behavior. Symbolic innovation, reflected in patent quality and disclosure–R&D gaps, is readily detectable through standard databases and financial disclosures [26,28]. Intermittent innovation, captured by R&D expenditure volatility, can be quantitatively tracked over time using public financial statements [15,47]. The relative transparency of these two behaviors enables financiers to embed conditionality clauses and inter-temporal penalties into funding contracts, rendering them potentially effective disciplinary tools. By contrast, displaced innovation, the diversion of funds toward non-green projects, is inherently opaque and difficult for external financiers to verify ex post without mandatory project-level auditing or use-of-proceeds tracking mechanisms [12,48]. This information asymmetry creates a principal-agent problem wherein borrowing firms have both the incentive and the opportunity to misallocate sustainable finance proceeds. Consequently, we anticipate that sustainable finance policy may be less effective in curbing displaced innovation compared to the other two archetypes, suggesting that mitigating such opaque opportunism requires complementary governance mechanisms beyond the policy itself.

Accordingly, we posit the following hypothesis:

Hypothesis 2. *Sustainable finance policy narrows regional green innovation disparities by constraining strategic innovation behaviors of brown firms, yet this inhibitory effect is expected to be stronger for symbolic and intermittent innovation than for displaced innovation.*

2.2.3. The Impact of Patient Capital and ESG Ratings

Sustainable finance policy becomes more effective at restraining strategic innovation when brown firms have accumulated greater patient capital. By extending the investment-cycle preference of brown firms, patient capital encourages enterprises to invest resources in substantive innovation with a long payback period rather than short-term compliance-oriented strategic innovation [51]. This phenomenon primarily arises from the ability of patient capital to mitigate the risks associated with financing maturity mismatches, alleviate shareholder pressure for short-term performance, and enhance tolerance for technical trial and error [52,53]. Therefore, for regions lagging in green innovation, cultivating patient capital is a necessary condition to catch up with frontier regions.

In addition, ESG ratings serve as an external market signal that bolsters the effectiveness of sustainable finance policy. Specifically, brown firms that achieve high ratings are more closely watched by stakeholders [54]. Should such firms pursue strategic innovation, they will encounter increased capital costs and potential investor flight [55]. Meanwhile, ESG disclosure rules force companies to make public roadmaps for technology upgrades and increase the traceability of strategic innovation behaviors [56]. Consequently, ESG ratings effectively identify brown firms with high transformation potential, enhancing capital allocation efficiency in regions lagging in green innovation and accelerating its convergence to developed areas.

Crucially, patient capital and ESG ratings operate through distinct but complementary channels [57]. Patient capital primarily disciplines intermittent innovation by providing tolerance for R&D fluctuations, while ESG ratings primarily discipline symbolic and displaced innovation by enhancing the detectability of disclosure-performance gaps and fund diversion. This division of labor suggests a synergistic governance system in which internal investment horizons and external market scrutiny jointly reinforce the effectiveness of sustainable finance policy across all three strategic innovation archetypes.

Accordingly, we posit the following hypothesis:

Hypothesis 3. *With the synergy of patient capital and ESG ratings, sustainable finance policy is more effective in narrowing regional green innovation disparities.*

3. Methodology

3.1. Econometric Framework

First, we exploit the publication of the China Green Bond Endorsed Project Catalogue in December 2015 as an exogenous policy shock. This policy is particularly suited for a difference-in-differences (DID) design for two reasons. First, the Catalogue was introduced as a nationwide guideline, not as a response to regional conditions. Its timing and scope are external to firm-level or regional green innovation trends. Second, the policy applies only to firms in six designated brown industries. This creates a natural treatment group (eligible brown firms) and a control group (other brown firms not covered by the Catalogue). Accordingly, we construct a DID framework to estimate the gap-narrowing effect of sustainable finance policy [16,58]:

$$GINDIS_{it} = \alpha_0 + \alpha_1 SUSFIN_{it} + \alpha_2 Controls + \alpha_3 i.Firm + \alpha_4 i.Year + \alpha_5 i.City + \varepsilon_{it} \quad (1)$$

where the dependent *GINDIS* variable captures regional disparity in green innovation, while the independent *SUSFIN* variable represents the sustainable finance policy. Controls is a set of covariates. Subscripts *i* and *t* index firms and time, and ε is a random disturbance with zero expectation. We control for firm, year, and city fixed effects. The estimated coefficient on *SUSFIN* is α_1 . A significantly negative α_1 would support the hypothesis that

sustainable finance policy narrows regional green innovation disparities; a significantly positive α_1 would indicate a widening effect.

Second, we test the mechanism through which sustainable finance policy narrows regional green innovation disparities. Drawing on our theoretical analysis, we posit that suppressing strategic innovation among brown firms is a key channel. To empirically validate this mechanism, we estimate the following model:

$$SYMINN_{it} = \beta_0 + \beta_1 SUSFIN_{it} + \beta_2 Controls + \beta_3 i.Firm + \beta_4 i.Year + \beta_5 i.City + \varepsilon_{it} \quad (2)$$

$$INTINN_{it} = \theta_0 + \theta_1 SUSFIN_{it} + \theta_2 Controls + \theta_3 i.Firm + \theta_4 i.Year + \theta_5 i.City + \varepsilon_{it} \quad (3)$$

$$DISINN_{it} = \rho_0 + \rho_1 SUSFIN_{it} + \rho_2 Controls + \rho_3 i.Firm + \rho_4 i.Year + \rho_5 i.City + \varepsilon_{it} \quad (4)$$

where the *SYMINN*, *INTINN*, and *DISINN* variables represent the three archetypes of strategic innovation behavior. β_1 , θ_1 , and ρ_1 are the coefficients of sustainable finance policy. Significantly negative β_1 , θ_1 , and ρ_1 would support the hypothesis that sustainable finance suppresses strategic innovation, whereas significantly positive β_1 , θ_1 , and ρ_1 would suggest a reinforcing effect.

Finally, the extent to which sustainable finance policy succeeds may vary with governance conditions. We examine this possibility by focusing on internal and external factors. Specifically, we incorporate patient capital and ESG ratings into Model (1) as moderating variables. Patient capital captures the long-term orientation of a firm's investors, while ESG ratings reflect external market scrutiny. By including interaction terms between *SUSFIN* and these moderators, we test whether patient capital and ESG ratings enhance or weaken the gap-narrowing effect of sustainable finance policy:

$$GINDIS_{it} = \delta_0 + \delta_1 SUSFIN_{it} + \delta_2 PATCAP_{it} + \delta_3 SUSFIN_{it} \times PATCAP_{it} + \delta_4 Controls + \delta_5 i.Firm + \delta_6 i.Year + \delta_7 i.City + \varepsilon_{it} \quad (5)$$

$$GINDIS_{it} = \chi_0 + \chi_1 SUSFIN_{it} + \chi_2 ESG_{it} + \chi_3 SUSFIN_{it} \times ESG_{it} + \chi_4 Controls + \chi_5 i.Firm + \chi_6 i.Year + \chi_7 i.City + \varepsilon_{it} \quad (6)$$

$$GINDIS_{it} = \psi_0 + \psi_1 SUSFIN_{it} + \psi_2 PATCAP_{it} + \psi_3 ESG_{it} + \psi_4 SUSFIN_{it} \times PATCAP_{it} + \psi_5 SUSFIN_{it} \times ESG_{it} + \psi_6 SUSFIN_{it} \times PATCAP_{it} \times ESG_{it} + \psi_7 Controls + \psi_8 i.Firm + \psi_9 i.Year + \psi_{10} i.City + \varepsilon_{it} \quad (7)$$

where *PATCAP* and *ESG* denote patient capital and ESG ratings, respectively. In Model (5), negative signs on both δ_1 and δ_3 would suggest that patient capital reinforces the gap-narrowing effect of sustainable finance policy. In Model (6), negative χ_1 and χ_3 would indicate that ESG ratings strengthen this effect. Significantly negative values of both ψ_1 and ψ_6 in Model (7) also proves that there is a synergistic governance effect between sustainable financial policies and patient capital, as well as ESG ratings.

3.2. Variables

3.2.1. Dependent Variable: Regional Green Innovation Disparity (*GINDIS*)

This study quantifies regional green innovation disparities by comparing the green innovation capacity of brown firms across northern and southern China. While traditional metrics like the Gini coefficient can effectively measure developmental disparities at national or regional levels, they fail to capture detailed firm-level information, thereby limiting their applicability in panel data models. To overcome this limitation, we employ the technique proposed by Wang et al. and use a deviance index to measure regional green innovation disparities [59]. The core computational formula is expressed as follows:

$$GINDIS_{it} = VAR(GIN_{it}^{n(s)}, \overline{GIN_{it}^{s(n)}}) \quad (8)$$

where *GINDIS* measures regional green innovation disparity and *GIN* is the log-transformed green patent count. The *s* and *n* superscripts refer to southern and northern China, respectively, and *i* and *t* index firms and years. The equation captures the variance between the regional average of green patents in one area and the firm-level value in the other. Higher variance values indicate a larger north–south gap in green innovation capabilities. The analysis covers 1073 brown firms located in 30 provinces, divided by the Qinling–Huaihe line. The northern region includes Heilongjiang, Jilin, Liaoning, Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, Inner Mongolia, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces. The southern region includes Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Chongqing, Sichuan, Yunnan, Hubei, Hunan, Guangdong, Guangxi and Hainan provinces. Due to data availability, Tibet, Hong Kong, Macao, and Taiwan are excluded from our analysis.

A potential concern with this geographic delineation is that certain provinces straddling the Qinling–Huaihe line are deeply integrated into broader economic corridors—most, notably the Yangtze River Delta (YRD) region encompassing Jiangsu, Anhui, and Zhejiang. Firms in these provinces may benefit from localized green technology spillovers and intra-regional knowledge diffusion independent of the 2015 sustainable finance policy shock, potentially biasing our estimates of the gap-narrowing effect. To address this concern, we implement two supplementary strategies in our robustness checks: (i) we exclude provinces that are official members of the YRD Economic Zone (Shanghai, Jiangsu, Zhejiang, and Anhui) from the sample to test whether our results are driven by these economically integrated areas, and (ii) we control for city-level green innovation spillovers by including the annual average green patent stock of neighboring cities within a 200 km radius as an additional covariate. These strategies allow us to isolate the policy effect from confounding regional spillovers.

3.2.2. Independent Variable: Sustainable Finance Policy (*SUSFIN*)

The December 2015 issuance of the China Green Bond Endorsed Project Catalogue gave brown firms access to sustainable financing [16]. Using this regulatory change, we construct a binary indicator, *SUSFIN*, coded as 1 for firm-year observations, where (i) the firm belongs to a Catalogue-listed brown industry and (ii) the year is 2016 or later. *SUSFIN* equals 0 otherwise.

3.2.3. Mechanism Variable: Strategic Innovation

(1) Symbolic Innovation (*SYMINN*)

Symbolic innovation refers to firm behavior in which patent applications or environmental disclosures are undertaken primarily for compliance or reputation purposes, without corresponding R&D investment or genuine knowledge generation. Following prior studies on patent quality [26,28], we adopt a two-step identification strategy. First, we calculate the ratio of green patent applications to R&D expenditure for each firm year. Second, we code a firm year as 1 if (i) this ratio exceeds the industry-year mean by more than one standard deviation and (ii) the firm's green patents receive zero citations within three years of application. This approach captures firms that generate a high volume of low-quality patents with no demonstrable technological impact.

(2) Intermittent Innovation (*INTINN*)

Intermittent innovation refers to firm behavior characterized by sharp, opportunistic fluctuations in R&D expenditure timed to coincide with policy evaluation or subsidy

application windows. Following Park et al., we measure intermittent innovation using the standard deviation of R&D expenditure growth rates over a three-year rolling window [15]. A firm year is coded as 1 if this rolling standard deviation exceeds the industry-year mean by more than one standard deviation, indicating a stop–start R&D trajectory that prevents persistent knowledge accumulation.

(3) Displaced Innovation (*DISINN*)

Displaced innovation refers to firm behavior in which sustainable finance funds are channeled toward low-risk, non-green projects that satisfy immediate compliance requirements but fail to advance the green technological frontier. Due to data availability constraints on direct use-of-proceeds tracking, we adopt a proxy approach: we measure the annual change in the share of green patents in a firm's total patent portfolio. A firm year is coded as 1 if this share declines by more than 10 percentage points relative to the three-year pre-financing-period average, indicating that resources are being redirected away from green technological advancement [12,48].

3.2.4. Moderating Variables

(1) Patient Capital (*PATCAP*)

Patient capital differs from traditional capital in its long-term focus. To capture this, we use two proxies: strategic equity (*PATCAP_1*) and relational debt (*PATCAP_2*). Strategic equity is measured by the ownership share of strategic institutional investors [60,61]. We identify these investors in two steps. First, for each institutional investor (*s*) and each listed firm (*i*), we compute the total holding period (T_{si}) over the sample period. Second, we calculate the average holding duration of investor *s* across all firms in their portfolio: $\overline{T_s} = (1/n_s) \sum_{i=1}^{n_s} T_{si}$. A strategic investor is identified when $T_{si} > \overline{T_s}$. *PATCAP_1* is the sum of shareholding ratios of all such investors in firm *i*. Moreover, *PATCAP_2* is the ratio of long-term liabilities (e.g., long-term loans, payable bonds, and long-term payables) to total liabilities [62].

(2) ESG Ratings (*ESG*)

We adopt the Sino-Securities ESG Index, which rates ESG performance on a nine-tier scale (C to AAA) and converts these ratings into numerical scores from 1 to 9 [63]. As an independent third-party evaluator, Sino-Securities systematically consolidates corporate disclosure data through voluntary reporting mechanisms while integrating supplementary information from authoritative sources including media disclosures and regulatory filings.

3.2.5. Control Variables

Firms differ in many ways that could affect their green innovation performance. To account for this heterogeneity, we include several firm-level control variables guided by prior studies [63,64]. Specifically, we control for listing age (*LISTYEAR*); firm size, as measured by the natural log of total employees (*SIZE*); cash holdings (*CASH*); return on equity (*ROE*); asset growth (*GROWTH*); the debt-to-equity ratio (*DER*); institutional ownership (*INS*); and a state-owned enterprise dummy (*STATE*). *STATE* equals 1 for SOEs and 0 otherwise. Continuous variables with skewed distributions are log-transformed.

3.3. Data

The study covers 1073 brown firms listed on China's Shanghai and Shenzhen stock exchanges over the 2011–2023 period. This timeframe gives us six years before the sustainable finance policy (2011–2015) and seven years after (2016–2023), enabling a robust assessment of the policy's impact. The sample is constructed following the September 2010 mandate by China's Ministry of Environmental Protection, which required 16 high-pollution industries (thermal power, steel, cement, and mining, among others) to file annual environmental

reports. Using the Catalogue’s classification, we assign 358 Catalogue-eligible firms to the treatment group and the remaining brown firms to the control group. Firms under Special Treatment (ST) are excluded due to financial anomalies that could compromise empirical validity. Financial and ESG data are drawn from the Wind Financial Terminal and CSMAR database, while green patent data are obtained from the CNRDS platform. Table 1 presents summary statistics.

Table 1. Summary statistics of key variables.

	Variable Description	Variables	Obs	Mean	Std. Dev.	Min	Max
Dependent variable	Regional green innovation disparity	<i>GINDIS</i>	10,276	0.4411	1.0186	0.0001	19.7581
Independent variable	Sustainable finance policy	<i>SUSFIN</i>	10,276	0.2557	0.4963	0	1
Mechanism variables	Symbolic innovation	<i>SYMINN</i>	9740	0.2173	0.5471	0	1
	Intermittent innovation	<i>INTINN</i>	9576	0.1697	0.3632	0	1
	Displaced innovation	<i>DISINN</i>	8864	0.275	0.3240	0	1
Moderating variables	Patient capital	<i>PATCAP_1</i>	9143	0.4540	0.2149	0.0034	0.8930
		<i>PATCAP_2</i>	9143	0.1234	0.1892	0	0.6800
	ESG ratings	<i>ESG</i>	9437	6.2471	1.1429	1	9
Controlled variables	Listing age	<i>LISTYEAR</i>	10,276	2.7559	0.4985	0	4.1431
	Firm size	<i>SIZE</i>	10,276	3.4901	1.5021	−3.0441	10.2158
	Cash holdings	<i>CASH</i>	9324	0.8064	1.7337	−8.2964	8.2070
	Return on equity	<i>ROE</i>	10,276	0.0495	0.2295	−9.6459	7.4451
	Asset growth	<i>GROWTH</i>	10,064	0.5651	12.5760	−0.9702	944.0995
	Debt-to-equity ratio	<i>DER</i>	10,276	0.4165	0.2456	0.0075	10.0816
	Institutional ownership	<i>INS</i>	9934	0.6567	0.5247	0.0060	4.0500
	State-owned enterprise	<i>STATE</i>	10,276	0.3197	0.4664	0	1

Sources: Prepared by the authors based on the sample employed in this study.

4. Analysis of Results

4.1. Main Results

Table 2 reports a significant negative estimate for *SUSFIN* in Model (1). We interpret this as evidence that sustainable finance policy helps close the regional green innovation divide. Hypothesis 1 is verified. Enterprises are the primary actors in green innovation. Their ability to secure funding fundamentally determines regional innovation capacity. Notably, traditional green finance systems have long excluded brown firms from financial support, depriving them of resources critical for transition [11]. Such structural exclusion has hindered green innovation capabilities in regions dominated by brown industries, amplifying inter-regional disparities. However, by establishing dedicated financing channels and transitional support mechanisms, sustainable finance policies provide targeted financial assistance to brown firms with transformation potential in lagging regions [45]. In short, this targeted financing approach has unlocked innovative capacity in brown firms and helped close the green innovation gap between regions.

Table 2. The gap-narrowing effect of sustainable finance policy.

Variables	<i>GINDIS</i> (1)	<i>GINDIS</i> (2)	<i>GINDIS</i> (3)	<i>GINDIS</i> (4)
<i>SUSFIN</i>	−0.3816 *** (−5.74)	−0.3500 *** (−3.12)	−0.2919 *** (−3.16)	−0.2143 ** (−2.23)
Controls	No	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Table 2. Cont.

Variables	GINDIS (1)	GINDIS (2)	GINDIS (3)	GINDIS (4)
Year FE	No	No	Yes	Yes
City FE	No	No	Yes	Yes
Robust SE	Yes	Yes	Yes	Yes
Firm-clustered SE	No	No	No	Yes
R ²	0.0253	0.2007	0.2301	0.2015
Obs.	8846	8846	8846	8846

Note: t-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$. Sources: Prepared by the authors based on the sample employed in this study.

4.2. Robustness Test

4.2.1. Parallel Trend Test

To confidently attribute post-2016 changes to sustainable finance, we must rule out pre-existing divergent trends between treatment and control groups. Following Jacobson et al. and Dobkin et al., we implement an event study that generates time dummies for each pre-2016 period [65,66]. If these pre-policy coefficients are statistically zero, the parallel-trends condition holds, meaning the two groups evolved similarly before the intervention.

Figure 3 shows that *SUSFIN* coefficients are insignificant before 2016, confirming the parallel-trends assumption. After 2016, the coefficients turn significantly negative and trend downward, indicating that sustainable finance policy's narrowing effect on regional green innovation disparities has strengthened over time.

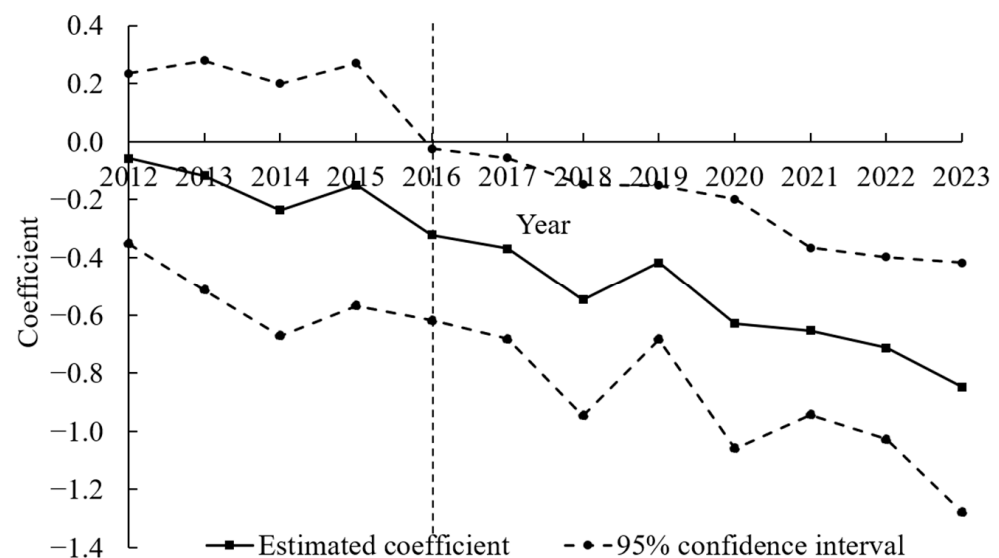


Figure 3. Parallel trend test.

4.2.2. Placebo Test

A potential threat to causal inference is that time-varying unobserved variables could be responsible for the observed effects. To mitigate this concern, we implement a placebo test with 1000 random reassignments of treatment status [67]. As shown in Figure 4, the estimated coefficients are centered near zero and generally insignificant, indicating that our baseline estimates do not reflect random noise or specification errors. Thus, this placebo analysis bolsters the statistical reliability of our main conclusions.

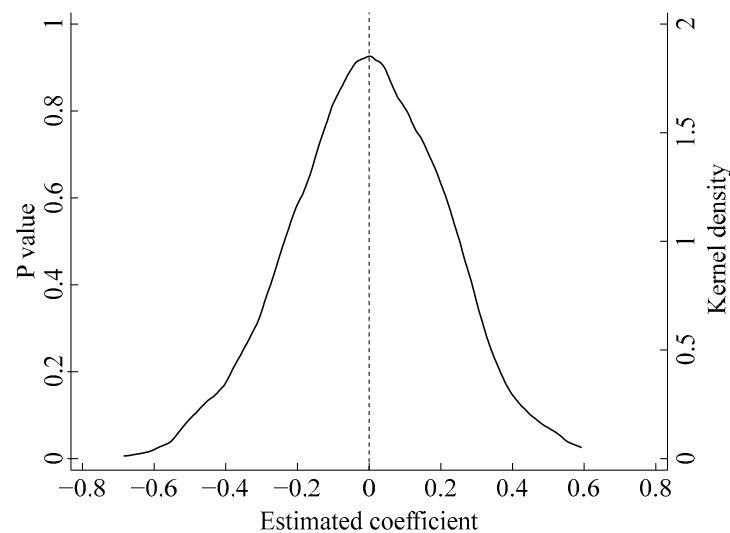


Figure 4. Placebo test.

4.2.3. Convergence Effect Test

Economic convergence theory can be extended to the spatial dimension to understand regional green innovation disparities [68]. Thus, we develop a convergence model to investigate whether sustainable finance policy promotes convergence in these regional gaps:

$$\ln\left(\frac{GINNO_{it}}{GINNO_{it-1}}\right) = \varphi_0 + \varphi_1 \ln(GINNO_{it-1}) + \varphi_2 SUSFIN \times \ln(GINNO_{it-1}) + \varphi_3 i.Firm + \varphi_4 i.Year + \varphi_5 i.City + \varepsilon_{it} \quad (9)$$

where *GINNO* is the green innovation capability measure. Our key coefficients are φ_1 and φ_2 . A negative sign on φ_1 suggests convergence: less capable firms catch up. A negative sign on φ_2 indicates that sustainable finance policy has expedited this catching-up process.

Column 1 of Table 3 shows that $\ln(GINNO_{it-1})$ and its interaction with *SUSFIN* are both negative and significant. This suggests that sustainable finance policy helps balance green innovation across regions. These results further reinforce the robustness of our baseline findings.

Table 3. The results of robustness tests.

Variable	Convergence Effect Test	Controlling Another Innovation Policy	Instrumental Variable		Controlling the Effect of Regional Spillovers	
	$\ln(GINNO_{it}/GINNO_{it-1})$ (1)	<i>GINDIS</i> (2)	First Stage <i>SUSFIN</i> (3)	Second Stage <i>GINDIS</i> (4)	<i>GINDIS</i> (5)	<i>GINDIS</i> (6)
$\ln(GINNO_{it-1})$	−0.6328 *** (−3.69)					
<i>SUSFIN</i> × $\ln(GINNO_{it-1})$	−0.0494 ** (−2.14)					
<i>SUSFIN</i>		−0.2518 ** (−2.06)		−0.2716 ** (−2.03)	−0.1988 *** (−2.93)	−0.2435 *** (−3.17)
<i>NIDZ</i>		−0.0692 ** (−2.14)				
<i>IV</i>			−0.1546 *** (−3.29)			
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Robust SE	Yes	Yes	Yes	Yes	Yes	Yes

Table 3. Cont.

Variable	Convergence Effect Test	Controlling Another Innovation Policy	Instrumental Variable		Controlling the Effect of Regional Spillovers	
	$\ln(\text{GINNO}_{it}/\text{GINNO}_{it-1})$ (1)	<i>GINDIS</i> (2)	First Stage <i>SUSFIN</i> (3)	Second Stage <i>GINDIS</i> (4)	<i>GINDIS</i> (5)	<i>GINDIS</i> (6)
Firm-clustered SE	Yes	Yes	No	No	Yes	Yes
R ²	0.3617	0.3017			0.2847	0.3274
Obs.	7954	8846	8846	8846	6412	8846
F statistic				45.27		
[p value]				[0.0000]		
Hansen J statistic				6.2170		
[p value]				[0.9531]		

Note: t-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$. Sources: Prepared by the authors based on the sample employed in this study.

4.2.4. Controlling Another Innovation Policy

A potential confounder is the presence of other innovation policies during our sample period. To isolate the effect of sustainable finance policy, we explicitly control for other programs in our regressions. The National Independent Innovation Demonstration Zones, a pivotal innovation incentive initiative in China, have effectively stimulated corporate innovation across multiple pilot cities [69]. To control for this policy's impact, we introduce a dummy variable (*NIDZ*) into Model (1), indicating whether brown firms are located within pilot cities.

The estimates in Table 3, Column (2), reveal that *SUSFIN* and *NIDZ* both negatively and significantly affect *GINDIS*. Thus, even after accounting for potential confounding from another innovation policy, our core finding that sustainable finance policy helps close regional green innovation gaps remains robust.

4.2.5. Instrumental Variable

One concern with our baseline specification is that causality could flow from green innovation performance to policy eligibility rather than the other way around. To address this reverse-causality threat, we employ an instrumental variable approach. Geographical factors are strongly exogenous. The minimum distance between brown firms and major financial hubs (Beijing, Shanghai, and Shenzhen) is therefore a theoretically valid instrument. However, as geographical distances remain time-invariant and might be absorbed by fixed effects, we follow Song et al. by constructing a time-varying provincial sustainable finance development index [70]. Specifically, this index measures the ratio of interest expenditures in six high-energy industries to total interest expenditures in industrial enterprises. The six energy-intensive industries are chemical raw material and chemical product manufacturing; nonmetallic mineral products; ferrous metal smelting; the rolling, non-ferrous metal smelting and processing industry; the oil processing and coking and nuclear fuel processing industry; and the electricity, heat production, and supply industry. Finally, we combine geographical distance with the interest expenditure ratio (*IV*), with lower interaction-term values indicating higher sustainable finance development levels.

The 2SLS results for Model (1) are shown in Table 3, Columns (3)–(4). The first-stage estimates confirm that *IV* and *SUSFIN* have a significant negative association. The second stage confirms that *SUSFIN* remains negative and significant. The F-statistic exceeds weak-instrument thresholds, and the Hansen J test does not reject over-identification. These results confirm that sustainable finance policy significantly narrows regional green innovation disparities, even after addressing endogeneity.

4.2.6. Controlling the Effect of Regional Spillovers

To rule out the possibility that our baseline results are confounded by green innovation spillovers from the Yangtze River Delta Economic Zone, we re-estimate Model (1) after excluding firms located in Shanghai, Jiangsu, Zhejiang, and Anhui, the four official member provinces of the YRD region. These provinces are characterized by high intra-regional mobility of capital, talent, and technology, which may generate localized green innovation externalities independent of the sustainable finance policy. As shown in Column 5 of Table 3, the coefficient on *SUSFIN* remains negative and statistically significant, indicating that our main finding is not driven by firms in YRD provinces.

Furthermore, we augment the baseline specification with a city-level green innovation spillover control, measured as the annual average green patent stock of cities within a 200 km radius. Column (6) of Table 3 shows that the inclusion of this spillover term does not materially alter the significance or magnitude of the *SUSFIN* coefficient. These results confirm that our estimated gap-narrowing effect is robust to the potential bias introduced by geographically proximate economic corridors.

4.3. Mechanism Analysis

To test whether sustainable finance policy narrows regional green innovation disparities through the suppression of strategic innovation and whether this suppression operates differentially across the three archetypes, we estimate Models (2)–(4). Table 4 reports the results.

Table 4. Strategic innovation response to sustainable finance policy.

Variable	<i>SYMINN</i> (1)	<i>INTINN</i> (2)	<i>DISINN</i> (3)
<i>SUSFIN</i>	−0.0372 *** (−3.21)	−0.0268 ** (−2.07)	−0.0154 (−1.12)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Robust SE	Yes	Yes	Yes
Firm-clustered SE	Yes	Yes	Yes
R ²	0.2746	0.2120	0.2028
Obs.	7450	7206	6983

Note: t-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$. Sources: Prepared by the authors based on the sample employed in this study.

Column (1) reports the effect of sustainable finance policy on symbolic innovation. The coefficient of *SUSTFIN* is negative and statistically significant at the 1% level, indicating that sustainable finance policy significantly attenuates firms' engagement in symbolic patenting activities. This finding is consistent with the view that funding conditionality—requiring verifiable R&D outputs and penalizing disclosure-performance gaps—most directly disciplines surface-level compliance behaviors [48]. By tightening the link between financing eligibility and demonstrable R&D commitment, sustainable finance raises the implicit cost of symbolic innovation, discouraging firms from pursuing low-quality patent applications that contribute no genuine knowledge accumulation.

Column (2) shows that sustainable finance policy also exerts a negative and significant effect on intermittent innovation, albeit with a smaller magnitude than that observed for symbolic innovation. This result suggests that inter-temporal reward–penalty mechanisms, which penalize R&D volatility and reward sustained investment trajectories, gradually smooth out opportunistic fluctuations in R&D expenditure [50]. The relatively weaker effect

may reflect the fact that intermittent innovation is more deeply embedded in firms' short-term operational routines and thus requires longer observation windows to fully attenuate. Nevertheless, the significant coefficient confirms that sustainable finance contributes to the stabilization of R&D investment, a necessary condition for persistent knowledge accumulation in lagging regions.

Column (3) reveals that the coefficient of *SUSFIN* on *DISINN* is negative but statistically insignificant, suggesting that sustainable finance policy, in its current form, does not significantly redirect displaced innovation. This null finding carries important theoretical implications. Unlike symbolic innovation (which is readily detectable through patent quality metrics) or intermittent innovation (which can be tracked through R&D volatility), displaced innovation involves the qualitative allocation of funds across project categories, which is inherently opaque and difficult to monitor through standard disclosure mechanisms [12].

The ineffectiveness of current policy in curbing displaced innovation underscores a critical limitation: while sustainable finance can discipline surface-level opportunism and R&D timing behaviors, it struggles to address deeper forms of resource misallocation whereby firms satisfy compliance on paper while substantively diverging from green transition goals. Unlike the other two archetypes, displaced innovation involves the qualitative misallocation of funds across project categories, which is a form of opportunism that is inherently opaque and difficult to verify through standard disclosure or output metrics. While a firm's total patent count or R&D expenditure volatility is publicly observable and subject to contractual penalties, the ultimate use of funds for genuine green projects versus low-risk non-green alternatives is far more challenging for financiers to monitor and enforce ex post.

Collectively, these findings support Hypothesis 2. The differentiated pattern of the strongest effect on symbolic innovation, moderate effect on intermittent innovation, and insignificant effect on displaced innovation validates our typological approach and reveals the nuanced ways in which sustainable finance reshapes corporate R&D behavior. Critically, the null result for displaced innovation suggests that addressing this archetype may require complementary governance mechanisms beyond the policy itself.

4.4. The Synergy of Patient Capital and ESG Ratings

Columns (1) and (2) of Table 5 present the moderating effects of patient capital, measured by two complementary proxies: strategic equity (*PATCAP_1*) and relational debt (*PATCAP_2*). In both specifications, the coefficient of *SUSFIN* remains negative and significant, confirming the baseline gap-narrowing effect. Notably, the $SUSFIN \times PATCAP_1$ and $SUSFIN \times PATCAP_2$ interaction terms are both negative and statistically significant, indicating that patient capital amplifies the gap-narrowing effect of sustainable finance policy. These findings suggest that patient capital operates through two channels. Strategic equity mitigates managerial short-termism, particularly attenuating symbolic and intermittent innovation by aligning long-term incentives with genuine R&D commitment [52,53]. Relational debt provides stable capital and, crucially, compensates for the policy's weakness against displaced innovation: long-term creditors have stronger incentives to monitor fund allocation and enforce covenant compliance, supplying a project-level governance function that policy alone cannot replicate [62]. However, this governance channel is contingent upon a firm having a sufficient long-term debt presence; in our sample, over 70% of firm-year observations exhibit a long-term debt ratio below 30% of total liabilities, meaning that for the majority of brown firms, creditor-based monitoring remains largely inactive. This finding also explains why the policy's average effect on displaced innovation is insignificant across the full sample.

Table 5. The impact of patient capital and ESG ratings on regional green innovation disparity.

Variable	<i>GINDIS</i> (1)	<i>GINDIS</i> (2)	<i>GINDIS</i> (3)	<i>GINDIS</i> (4)	<i>GINDIS</i> (5)
<i>SUSFIN</i>	−0.2457 *** (−3.44)	−0.2251 ** (−2.12)	−0.2275 ** (−1.99)	−0.2327 ** (−2.27)	−0.2327 ** (−2.11)
<i>PATCAP_1</i>	−0.1324 ** (−1.99)			−0.1137 ** (−2.37)	
<i>SUSFIN</i> × <i>PATCAP_1</i>	−0.0357 * (−1.74)			−0.0269 ** (−2.04)	
<i>PATCAP_2</i>		−0.5796 *** (−3.17)			−0.1279 ** (−2.28)
<i>SUSFIN</i> × <i>PATCAP_2</i>		−0.0649 *** (−3.65)			−0.0447 *** (−3.37)
<i>ESG</i>			0.4796 *** (2.98)	0.3274 *** (2.86)	0.4007 ** (2.34)
<i>SUSFIN</i> × <i>ESG</i>			−0.0476 ** (−2.36)	−0.0589 ** (−2.41)	−0.0417 * (−1.90)
<i>SUSFIN</i> × <i>PATCAP_1</i> × <i>ESG</i>				−0.0247 ** (−2.33)	
<i>SUSFIN</i> × <i>PATCAP_2</i> × <i>ESG</i>					−0.0327 * (−1.86)
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Robust SE	Yes	Yes	Yes	Yes	Yes
Firm-clustered SE	Yes	Yes	Yes	Yes	Yes
R ²	0.2458	0.2745	0.2579	0.2617	0.2264
Obs.	7109	7109	7109	7109	7109

Note: t-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sources: Prepared by the authors based on the sample employed in this study.

Column (3) reports the moderating effect of ESG ratings. The coefficient of *ESG* is positive and significant, which is unsurprising, given that firms with higher ESG ratings tend to be located in more developed regions with stronger green innovation capacity. This is consistent with prior findings that ESG performance is positively associated with firm-level innovation outputs [63]. More importantly, the *SUSFIN* × *ESG* interaction term is negative and significant, suggesting that ESG ratings strengthen the gap-narrowing effect of sustainable finance policy. This negative interaction indicates that ESG ratings enhance policy effectiveness by increasing the detectability and credibility of firms' green transition commitments. Specifically, high ESG ratings subject firms to greater scrutiny from analysts, media, and institutional investors [55]. When a high-ESG firm engages in symbolic innovation, the discrepancy between its public ESG claims and actual innovation performance becomes more readily detectable, triggering reputational penalties and capital-market sanctions. Similarly, ESG disclosure requirements force firms to publicly report their technology-upgrade roadmaps and progress milestones, increasing the traceability of intermittent innovation [56].

To test whether patient capital and ESG ratings jointly amplify the gap-narrowing effect of sustainable finance policy, we augment Model (7) with the *SUSFIN* × *PATCAP_1* × *ESG* and *SUSFIN* × *PATCAP_2* × *ESG* three-way interaction terms. Columns (4) and (5) of Table 5 report the results. The coefficients of both triple interaction terms are negative and statistically significant, indicating that the reinforcing effects of patient capital and ESG are not merely additive but synergistic. This triple synergy confirms that the governance

system operates as an integrated whole: sustainable finance provides the framework for institutional incentive, patient capital supplies long-term investment commitment and project-level monitoring, and ESG ratings enhance external accountability and reputational discipline. When all three layers are present, their combined effect on narrowing regional green innovation disparities exceeds the sum of their individual contributions [60]. This is consistent with the system-theoretic proposition that multi-level governance architectures generate emergent properties that single-layer interventions cannot achieve. Therefore, Hypothesis 3 is verified.

5. Discussion

Our empirical findings provide three key theoretical insights into the mechanisms governing spatial rebalancing in green innovation, extending current discourse on sustainable finance and regional development.

First, this study illuminates the spatial redistribution function of sustainable finance. Prior research has focused on its aggregate incentive effects for green innovation, largely overlooking this spatial dimension [24,25]. While existing literature has extensively documented how green finance channels capital toward low-carbon sectors [34], it has paid insufficient attention to the structural exclusion experienced by brown-industry regions, which is a critical driver of persistent spatial inequality. Our results demonstrate that sustainable finance serves not merely as a capital allocation tool but as a spatial equalizer, actively dismantling the self-reinforcing cycle of technological lock-in that consigns lagging regions to the periphery of green innovation networks [7]. This finding extends the ‘green marginalization’ thesis. It reveals a viable institutional pathway to counteract the Matthew effect in innovation resource distribution [49]. From a policy design perspective, this implies that financial instruments aimed at sustainability transitions must be evaluated not solely on the basis of their aggregate environmental outcomes but also on the basis of their capacity to redress spatial asymmetries. For emerging economies with core–periphery divides, sustainable finance offers a targeted mechanism to reconfigure innovation capital flows and break path-dependent trajectories. It complements traditional regional development policies that often fail to address the specific financial barriers facing brown industries.

Second and perhaps most critically, the null effect on displaced innovation reveals a structural loophole in the current sustainable finance auditing framework. Our findings demonstrate that while the policy effectively disciplines symbolic and intermittent innovation, it completely fails to prevent firms from diverting transition funds toward non-green projects that satisfy compliance on paper but substantively deviate from green transition goals [12,48]. This is not a marginal limitation but a fundamental institutional failure: the policy’s verification mechanism is designed to track quantitative outputs rather than the qualitative allocation of funds, creating a perverse incentive structure in which brown firms can publicly claim green financing while privately channeling capital into business-as-usual projects, which is a practice that constitutes precisely the greenwashing behavior that sustainable finance is supposed to combat [35]. This null effect is therefore a diagnostic signal of an auditing regime that lacks project-level use-of-proceeds tracking, independent ex post verification, and credible sanctions for fund diversion. This finding challenges the prevailing optimism that sustainable finance instruments inherently promote genuine green transitions; without rigorous enforcement, such policies risk becoming symbolic gestures that legitimize rather than rectify the spatial inequality they are designed to address. Consequently, we urge policymakers to prioritize mandatory project-level auditing, third-party verification protocols, and proportional penalty systems for non-compliant fund allocation to close this critical loophole.

A further theoretical implication concerns the potential for dynamic interactions across the three strategic innovation archetypes. As theorized in the Introduction, firms may combine multiple forms of opportunism simultaneously or sequentially transition between them as policy constraints evolve. For instance, a firm initially pursuing symbolic innovation to secure financing may shift toward displaced innovation once funded, exploiting the opacity of fund allocation [48]. If such strategic switching occurs, the policy's aggregate inhibitory effect on strategic innovation may be smaller than the sum of its individual effects on each archetype, as firms continuously re-optimize to evade detection. This reinforces our call for comprehensive auditing frameworks that monitor not only patent quality and R&D volatility but also the ultimate deployment of funds, which is a multi-layered approach capable of detecting adaptive responses across different forms of opportunism. While our empirical design does not explicitly model these transitions, future longitudinal research could trace how firms re-optimize their strategic behaviors over time in response to evolving policy regimes.

Lastly, our moderation analysis reveals the synergistic interplay between internal and external governance conditions, enriching the theoretical framework of policy effectiveness. While patient capital has been conceptualized as a critical enabler of long-term investment horizons [52,53] and ESG ratings have been recognized as mechanisms for market-based reputation constraint [55], prior research has typically examined these factors in isolation, neglecting their interaction with financial policy instruments. Our finding that both patient capital and ESG ratings amplify the gap-narrowing effect of sustainable finance suggests the existence of a governance multiplier effect, wherein internal capital commitment and external market scrutiny jointly reinforce institutional incentives. This theoretical insight advances the institutional economics perspective on sustainability transitions by demonstrating that policy effectiveness is contingent upon the broader governance ecosystem. For regions lagging in green innovation, this implies a sequential policy logic: cultivating patient capital and strengthening ESG infrastructure are not peripheral complements but essential preconditions that determine whether sustainable finance can achieve its intended spatial-rebalancing outcomes. Practically, this cautions against the simplistic adoption of sustainable finance policies in weak institutional environments, instead emphasizing the necessity of a holistic governance reform package.

6. Conclusions

Conventional green financial systems have long excluded brown firms. This structural bias reinforces spatial inequality in green innovation. As a result, regions dominated by brown industries find themselves increasingly marginalized from green development trajectories. This divergence, amplified by the Matthew effect, has institutionalized new forms of spatial inequality through technological exclusion. Against this backdrop, sustainable finance emerges as a critical institutional innovation to recalibrate capital flows by enhancing financial accessibility in lagging regions. Through a focused examination of China's north-south green innovation divide, this study demonstrates how strategically designed sustainable finance policies can narrow regional disparities, offering insights for global sustainable transition governance.

Employing a DID framework to analyze the China Green Bond Endorsed Project Catalogue, we find that sustainable finance policy significantly narrows regional green innovation disparities. This result is robust to IV estimation, placebo tests, and alternative specifications. Mechanism analysis reveals that sustainable finance operates by differentially suppressing three archetypes of strategic innovation—symbolic, intermittent, and displaced—each of which contributes to regional disparities through distinct pathways. Specifically, the policy effectively attenuates symbolic innovation by penalizing

surface-level patenting through funding conditionality and curtails intermittent innovation by smoothing R&D volatility through inter-temporal incentives yet, alone, fails to curb displaced innovation, where funds are diverted toward non-green projects. Moreover, the policy's effectiveness grows under the synergy of internal and external governance: patient capital and ESG ratings each serves to strengthen sustainable finance's capacity to reduce regional gaps in green innovation. Crucially, our triple interaction analysis confirms that when sustainable finance, patient capital, and ESG ratings operate in concert, their combined gap-narrowing effect exceeds the sum of their individual contributions. This demonstrates that the governance system, as a whole, governs what no single layer can govern alone.

To realize the full potential of sustainable finance, policymakers should adopt a three-fold strategy that aligns institutional design, market forces, and governance conditions. First, sustainable finance should serve as a complementary instrument alongside conventional green finance, specifically targeting brown firms with viable transformation potential in regions that lag in green innovation. Eligibility criteria should be calibrated to firms' technological absorptive capacity and transition readiness to avoid resource misallocation. Second, financial institutions need to actively track brown firms' strategic innovation tendencies and use sustainable finance as a disciplinary tool to encourage a shift toward substantive innovation. To close the transparency loopholes that currently enable fund diversion, we recommend linking disbursements to verifiable green performance milestones, conducting unscheduled project audits, incorporating digital tracking tools to enhance capital-flow traceability, and mandating independent third-party verification with publicly accessible results. Third, green innovation laggards should prioritize building patient capital, refining ESG ratings, and establishing complementary institutional conditions that enable sustainable finance to function effectively. Policies that incentivize the deepening of long-term debt markets and strengthen ESG disclosure requirements would enhance the governance synergy effect, thereby amplifying the gap-narrowing effect of sustainable finance policy.

While demonstrating the efficacy of sustainable finance policies, this study acknowledges two inherent limitations. Firstly, our findings are derived from China's unique institutional context and a pronounced north-south divide, which may limit their generalizability to other economies with different financial architectures and innovation ecosystems. Future research could extend our analytical framework to diverse national settings, such as other BRICS economies or OECD countries, to test the generalizability of our conclusions across varying institutional environments. Secondly, the long-term effects of policy necessitate longitudinal tracking of brown firms' strategic innovation behaviors. From a life-cycle perspective, subsequent work could trace how firms dynamically switch across the three strategic innovation archetypes—symbolic, intermittent, and displaced—in response to evolving policy regimes. Thirdly, our analysis centers on firm-level financing constraints and strategic innovation behaviors as the primary mechanism explaining regional disparities but does not fully account for broader macro-level factors. Future research could adopt a multi-level framework that integrates these institutional and technological system factors alongside financial mechanisms to provide a more comprehensive account of spatial rebalancing in green innovation.

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