sustainability

Review

Green Product and Process Innovation and Firm Performance: A Meta-Analytic Review

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Abstract

As organizations strive to balance environmental stewardship with economic competitiveness, understanding the performance implications of Green Innovation (GI) has become increasingly important. Although the nexus between Green Product Innovation (GPI), Green Process Innovation (GPrI), and organizational outcomes has attracted sustained scholarly attention, empirical evidence remains inconclusive. To reconcile these inconsistencies and delineate boundary conditions, this study synthesizes data from 48 empirical investigations (2012–2025) via a random-effects meta-analysis with the Hartung–Knapp adjustment and trim-and-fill procedures to strengthen statistical inference. Results reveal significant small-to-moderate positive associations between GI and environmental ($r = 0.172$), financial ($r = 0.191$), and innovation performance ($r = 0.143$). Notably, moderator analyses demonstrate a synergy premium, where Integrated GI measures significantly outperform isolated GPI or GPrI approaches ($r = 0.353$). Substantial heterogeneity exists ($I^2 = 91.2\%$), which is significantly moderated by innovation type, industry pollution intensity, geographic region, and research design. Our findings reinforce the Natural-Resource-Based View (NRBV) and the Dynamic Capabilities framework, highlighting that strategic returns depend on asset orchestration and contextual factors. We conclude that firms should adopt a holistic approach, integrating both product and process innovations to enhance competitive advantage in an incremental and context-contingent manner, while interpreting innovation-performance results cautiously given the limited evidence base.

Keywords: green innovation; green product and process innovation; corporate performance; environmental and financial performance; meta-analysis; natural-resource-based view (NRBV); ESG; sustainable innovation

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1. Introduction

Environmental sustainability has become a central concern for organizations navigating the complexities of global competition, regulatory pressures, and stakeholder expectations. Firms increasingly adopt environmentally oriented innovations not merely as compliance mechanisms but as strategic investments aimed at achieving superior environmental and economic outcomes.

Green Innovation (GI), broadly defined as the introduction of products, processes, or practices that reduce environmental harm or enhance resource efficiency, has been conceptualized as a pathway to sustainable performance [1]. Conceptually, GI is widely viewed as comprising two distinct dimensions: Green Product Innovation (GPI) and Green Process Innovation (GPrI).

GPI refers to changes in the goods or services offered that improve their environmental attributes, whereas GPrI denotes alterations in production or delivery processes that reduce ecological impacts [2]. As these innovation types gain prominence in both academic research and corporate strategy, the question of their performance implications has attracted sustained empirical attention. Throughout this manuscript, we use the term "Integrated GI" to refer explicitly to empirical studies that employ a composite construct to assess GPI and GPrI simultaneously, thereby distinguishing them from studies that measure these dimensions in isolation.

Empirical studies investigate how GPI and GPrI relate to diverse performance outcomes, including environmental indicators (e.g., emissions reduction), financial outcomes (e.g., profitability), and innovation performance (e.g., patenting activity or new product introductions) [3,4]. While numerous individual studies report positive associations between GI and specific performance metrics, the magnitude and significance of these effects vary widely across industry contexts, measurement approaches, and research designs. For example, Xie et al. [2] found that GPrI had a stronger positive effect on cost savings for manufacturing firms. In contrast, GPI was more strongly associated with market performance in service sectors [1,2]. Other studies suggest that regulatory environments and stakeholder pressures moderate the efficacy of green initiatives, with stronger effects emerging under stringent environmental policies [5,6].

The diversity of findings raises questions about the generalizability and robustness of conclusions drawn from individual studies. Meta-analysis offers a systematic approach to aggregating empirical results and deriving pooled estimates of effect sizes across studies, thus providing a clearer view of the central tendency of relationships and the extent of heterogeneity [7,8]. Prior meta-analytic work in this domain, such as the synthesis by Rahmani et al., has underscored a positive relationship between GI and environmental performance, yet also highlighted the variability of outcomes across contextual factors [9]. Similarly, Hızarcı-Payne et al. synthesized the field of environmental innovation research. They found that the relationship with firm performance exhibited considerable dispersion, suggesting the influence of moderators such as industry characteristics and measurement approaches [10].

Despite these advances, several methodological and substantive gaps remain. First, many meta-analytic syntheses have relied on conventional random-effects models without incorporating advanced inferential procedures such as the Knapp–Hartung adjustment, which accounts for uncertainty in the estimation of between-study variance and often yields more reliable confidence intervals for pooled effect sizes [11]. Second, assessments of publication bias, while common, often omit formal adjustment techniques, such as the trim-and-fill procedure, which imputes missing studies and recalibrates pooled estimates to address asymmetry in funnel plots [12]. Third, existing syntheses often conflate different outcome domains or treat GPI and GPrI interchangeably, potentially obscuring nuanced distinctions in how these innovation types contribute to specific performance dimensions.

This study addresses these gaps by conducting a comprehensive meta-analysis of 48 empirical studies examining the relationships between GI and performance outcomes. We explicitly differentiate between green product and process innovation and disaggregate results into three performance domains: environmental performance, financial performance, and innovation performance. Our analytical approach incorporates Knapp–Hartung (HK-SJ) corrected estimates and trim-and-fill adjustments to provide robust pooled effect sizes and to probe potential publication bias. By integrating heterogeneous findings across studies, we aim to clarify the overall strength and direction of the association between

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environmental innovation and organizational outcomes, identify sources of heterogeneity, and provide guidance for future theory development and empirical investigation.

The remainder of this paper is structured as follows. Section 2 outlines the theoretical foundations and develops hypotheses regarding the expected relationships between GI and performance outcomes. Section 3 describes the meta-analytic methodology, including literature search procedures, data coding protocols, effect size computation, and statistical models. Section 4 presents the results of the meta-analysis, including pooled effect sizes with HK-SJ adjustments, heterogeneity statistics, and publication bias diagnostics with trim-and-fill corrections. Section 5 discusses theoretical and practical implications, limitations, and avenues for future research. Section 6 concludes with a summary of key insights and recommendations for scholars and practitioners.

Figure 1 presents the research framework for the entire study, visually demonstrating the logical development and operational steps.

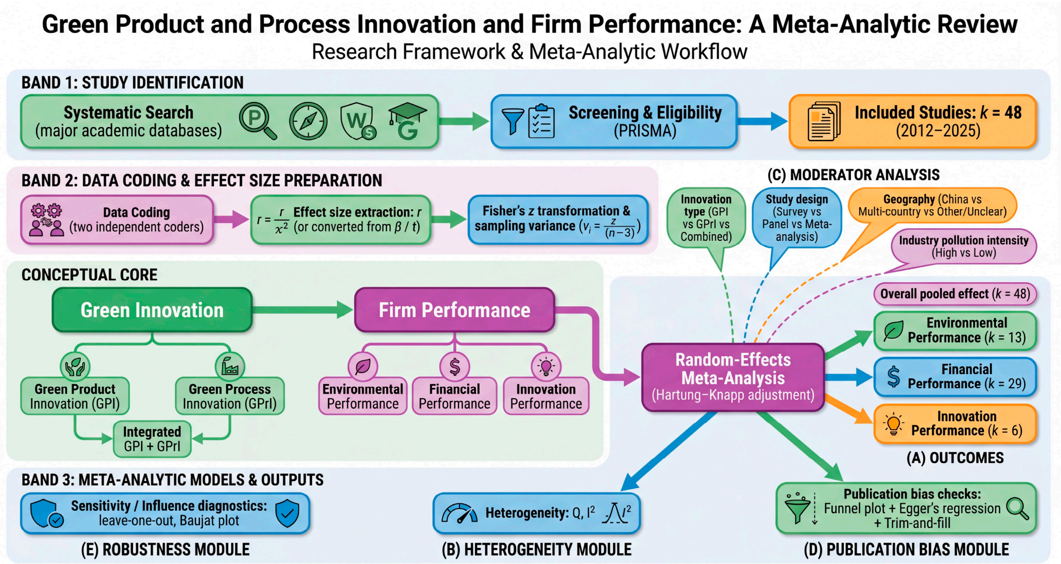

Figure 1. Research Framework.

2. Theory and Hypotheses

GI has become a critical driver of firms' sustainability strategies, where organizations aim to align environmental performance improvements with operational and financial benefits. Extant literature has examined the interplay between GPI and GPrI within various theoretical frameworks, particularly the Natural-Resource-Based View (NRBV) and Dynamic Capabilities Theory. These frameworks offer useful insights into how firms can gain a competitive advantage by integrating environmental considerations into their innovation strategies.

2.1. GI: Product vs. Process

Green Innovation (GI) can be broadly categorized into two types: Green Product Innovation (GPI) and Green Process Innovation (GPrI). GPI focuses on developing new products or modifying existing ones to minimize environmental harm, such as energy-efficient appliances or biodegradable packaging. On the other hand, GPrI refers to innovations in production processes aimed at reducing environmental impacts, such as improvements in energy efficiency, waste reduction, and resource use. Both GPI and GPrI contribute to a firm's sustainability strategy, but they operate through different mechanisms and are often associated with different outcomes [1].

Studies suggest that GPI and GPrI may not always act independently. In fact, they often complement each other, with GPrI enabling the implementation of GPI through efficient resource management and cost savings. This complementarity suggests that firms integrating both types of innovation may experience greater overall performance benefits. For example, GPrI might lower the costs of adopting new, greener technologies, thereby enhancing the financial feasibility of introducing new green products [1,13].

H1. *GPI and GPrI are both positively correlated with environmental performance.*

2.2. The Role of GI in Environmental Performance

The relationship between GI and environmental performance has been extensively studied, and the prevailing consensus is that GPI and GPrI contribute positively to environmental outcomes. By improving product design or manufacturing processes, firms can reduce their environmental footprint by decreasing greenhouse gas emissions, energy consumption, and material waste. This is particularly evident in industries such as manufacturing, where both GPI and GPrI can lead to substantial environmental gains [14].

Moreover, regulatory pressures, such as stringent environmental laws and policies, often encourage firms to adopt GI that align with government sustainability objectives. As such, firms that engage in GI not only enhance their environmental performance but also gain legitimacy in the eyes of regulators, consumers, and other stakeholders [15]. These dynamics underscore the critical role of regulatory environments in shaping the relationship between GI and environmental performance.

H2. *GI is positively associated with improvements in environmental performance.*

2.3. GI and Financial Performance

While the positive nexus between GI and environmental performance is well-documented, its impact on financial performance remains a subject of intense scholarly debate. From a traditional perspective, green initiatives are often seen as "non-productive" costs that require substantial capital expenditures in R&D and specialized equipment, potentially straining a firm's financial resources, especially for resource-constrained SMEs. Conversely, the NRBV and the Porter Hypothesis suggest that environmental investments can trigger "innovation offsets," in which the resulting efficiencies and market advantages outweigh compliance costs.

We argue that GPrI and GPI contribute to financial performance through distinct but complementary mechanisms. GPrI primarily enhances financial outcomes via internal operational efficiency. By optimizing production workflows, reducing resource consumption, and minimizing waste, GPrI enables firms to achieve cost leadership. These efficiency gains often translate into direct improvements in accounting-based metrics, such as return on assets (ROA) or net profit margins, by lowering the total cost of goods sold.

GPI, in contrast, creates financial value predominantly through external market differentiation. By introducing eco-friendly products that meet the increasing demand from environmentally conscious consumers, firms can command price premiums and capture new market segments. Furthermore, GPI bolsters corporate reputation and brand equity, which are critical for long-term intangible asset growth and market-based performance. Given that both internal cost-savings and external market expansion contribute to the firm's bottom line, we propose:

H3. *GPrI is positively associated with firm financial performance.*

H4. *GPI is positively associated with firm financial performance.*

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2.4. GI and Innovation Performance

GI can also contribute to broader innovation performance. Firms that engage in GI often develop new capabilities that enable them to innovate more effectively in other areas, such as technological development and product diversification. This aligns with the concept of absorptive capacity, where firms enhance their ability to recognize, assimilate, and apply new knowledge through their investment in innovation. As such, the adoption of GI, particularly GPI, can stimulate additional innovation activities, thereby improving the firm's overall innovation performance [16].

GPrI can also create a platform for further innovation by improving operational efficiencies and reducing environmental impact. For example, firms that innovate their production processes may gain insights into sustainable practices that can be applied to other areas of their operations, such as logistics, supply chain management, or customer engagement. Thus, GPrI can act as a stepping stone to new product innovations or service improvements [3].

H5. *GI (GPI and GPrI) is positively associated with broader innovation performance, including new product development and process improvements.*

2.5. Boundary Conditions of the GI–Outcome Relationship

While the direct effects of GI on firm performance are important, the relationship between GI and performance outcomes is often moderated by contextual factors such as industry type, firm size, geographic location, and regulatory environment. For instance, firms in high-pollution industries may exhibit more immediate and observable environmental improvements following GPI and GPrI adoption; however, such visibility does not necessarily imply larger overall performance returns, as compliance-driven adoption may reduce strategic differentiation [17]. Similarly, firms in regions with strong environmental regulations (e.g., the European Union or California) may be more likely to adopt GI, which can be associated with improved outcomes, although the magnitude of these benefits may vary across institutional settings [9].

Furthermore, firm size and organizational capabilities may moderate the effectiveness of GI. Larger firms with greater financial resources and R&D capabilities may be better positioned to implement GI and realize the associated financial and innovation performance benefits [9]. In contrast, SMEs may face greater barriers to adopting GI due to resource constraints and a lack of technological expertise.

Drawing on the contingency perspective of the NRBV, industry-level factors such as pollution intensity create distinct regulatory and competitive landscapes that shape the strategic value of green initiatives. In high-pollution sectors, GI is frequently driven by coercive isomorphism or strict regulatory compliance, which may lead to the standardization of practices and diminish their uniqueness as a source of competitive advantage. Conversely, in low-pollution industries, GI is more likely to represent a proactive differentiation strategy, enabling firms to capture premium market segments and enhance their reputations. Consequently, the performance returns on green investments are expected to vary significantly across different industrial contexts. Based on this logic, we propose:

H6. *Industry pollution intensity moderates the relationship between GI and firm performance, such that the association is stronger in low-pollution industries.*

2.6. Conclusion of Hypotheses Section

The hypotheses outlined above suggest that GI, whether in the form of product or process innovation, can significantly contribute to environmental, financial, and innovation performance outcomes. However, the magnitude and direction of these effects are likely to be influenced by contextual factors such as firm size, industry type, and regulatory environment. In the following sections, we will present the meta-analytic methodology used to test these hypotheses and provide robust pooled effect estimates for each performance domain.

3. Methods

3.1. Literature Search and Inclusion Criteria

We conducted a comprehensive systematic search to identify relevant empirical studies investigating the relationship between GI (both GPI and GPrI) and firm performance. We queried major academic databases, including Scopus, Web of Science, ScienceDirect and Google Scholar, using a Boolean search string encompassing keywords related to "green innovation," "product innovation," "process innovation," "firm performance," and "environmental performance," among others, covering the period from 2010 to 2025. The final search was executed on 20 June 2025. To ensure a high level of transparency and reproducibility, the study strictly follows the PRISMA 2020 guidelines. We selected studies for inclusion based on the following criteria:

1. They provided empirical evidence linking GPI or GPrI to at least one of the performance outcomes: environmental, financial, or innovation performance.
2. The study reported an effect size or sufficient statistical information (e.g., Pearson's correlation [r], t-statistics, or standardized β) that allowed for the calculation of a correlation coefficient or its transformation.
3. The study used the quantitative research design, including cross-sectional, longitudinal, and experimental studies, excluding case studies, purely conceptual papers, narrative reviews, or theoretical papers.
4. The study was published in a peer-reviewed journal, ensuring its methodological rigor.

A total of 48 studies were included in the final meta-analysis after applying the inclusion criteria and removing studies that did not meet these standards or lacked sufficient data for effect-size calculation. Although the included studies cover multiple regions (e.g., China, Europe, North America, and multi-country samples), the evidence base is geographically concentrated in China (approximately 70%), which may limit cross-regional generalizability; therefore, the pooled estimates should be interpreted as most representative of contexts characterized by strong regulatory steering and rapid ecological transition. The study strictly follows the PRISMA 2020 process, with specific details and steps shown in Figure 2. Because a small number of records included are meta-analyses, we treated each meta-analysis as a single independent record and verified that its underlying primary studies do not overlap with the primary-study dataset used in our main analysis; overlapping evidence was excluded to prevent double-counting.

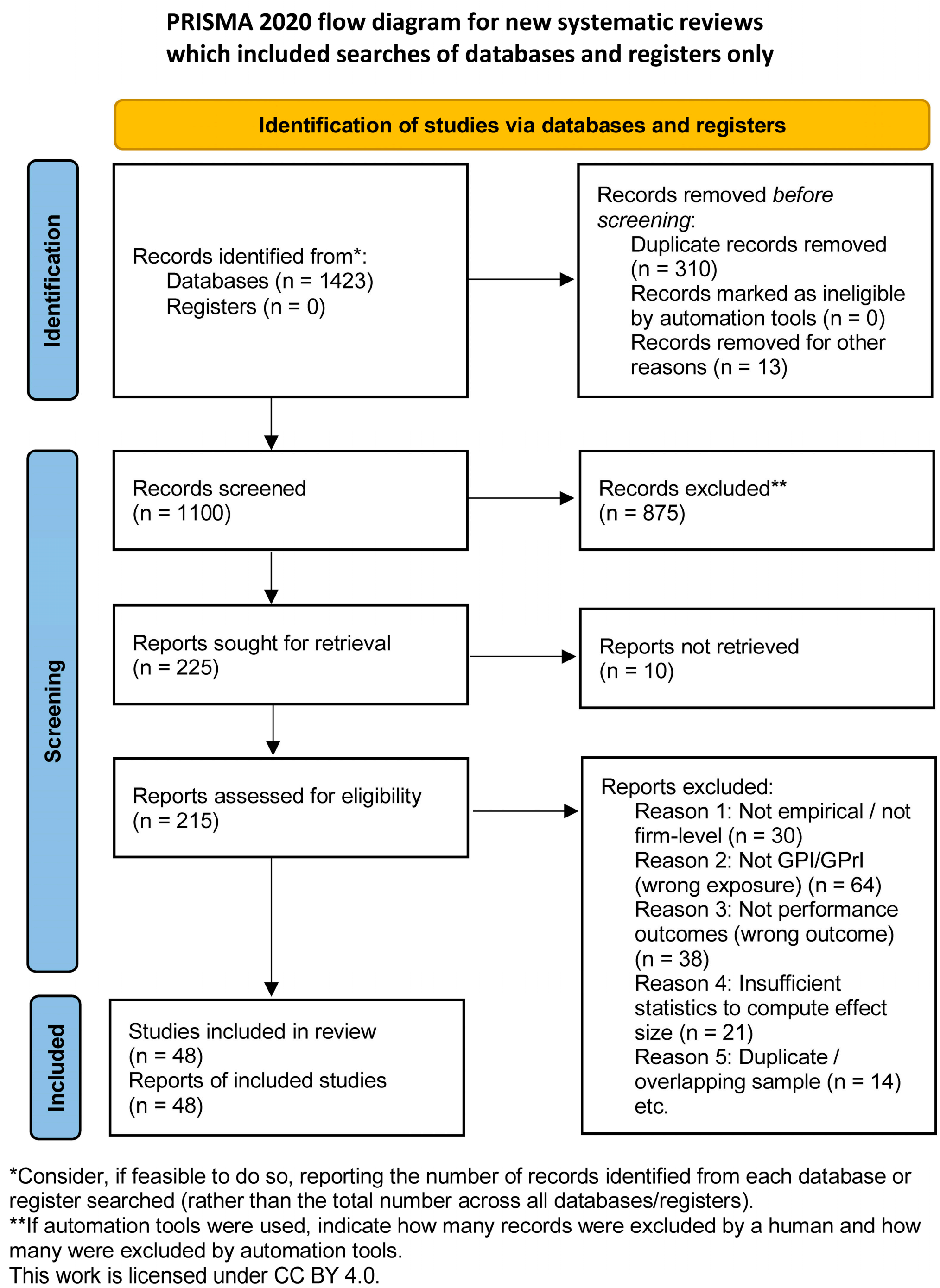

Figure 2. PRISMA 2020 flow diagram of study identification, screening, eligibility assessment, and inclusion for the meta-analysis on green product/process innovation and firm performance.

3.2. Data Coding and Effect Size Calculation

To ensure consistency and reliability, two independent coders extracted data from each included study. The extracted data included:

1. Study ID: Author(s) and year of publication.
2. Sample Size (n): Total number of observations used to compute the effect size.
3. Effect Size: The correlation coefficient (r) between GI (either GPI or GPrI) and the relevant performance outcome (environmental, financial, or innovation performance). If the reported effect size was not in the form of a correlation coefficient, it was converted into r using standardized β or t statistics where applicable.

4. Outcome Type: Environmental performance, financial performance, or innovation performance.
5. Innovation Type: We distinguished between studies that measured GPI and GPrI as separate constructs and those that utilized a single, composite construct. The category Integrated GI comprises studies that use a combined scale to measure overall GI. It does not represent an artificial aggregation of separate GPI and GPrI effect sizes; rather, it reflects a holistic measurement approach adopted by the original authors.
6. Study Design: Whether the study employed a panel data design, cross-sectional design, or meta-analytic synthesis.
7. Country/Region: The geographical focus of the study, such as China, multi-country, or other/unclear.

To enhance transparency and reproducibility, we applied explicit coding protocols for key moderators, with full decision rules documented in Appendices A.4–A.6. Innovation Type was coded as GPI, GPrI, or Integrated GI based on how each primary study operationalized green innovation (Appendix A.4). Specifically, studies that measured product and process dimensions using a single unidimensional (composite) GI scale were coded as Integrated GI, whereas studies measuring only product- or process-focused constructs were coded as GPI or GPrI. Industry Pollution Intensity was coded as High-pollution or Low-pollution following the classifications reported in the primary studies (e.g., heavy manufacturing/chemicals vs. other sectors), excluding mixed samples with no dominant sector (Appendix A.5). Finally, Geography was grouped into China, multi-country, and other/unclear (Appendix A.6).

We transformed effect sizes into Fisher's z scores to normalize the distribution of correlations. Fisher's z-transformation is commonly used in meta-analysis to stabilize the variance of correlation coefficients and improve the accuracy of pooled effect size estimates. The formula for Fisher's z-transformation is:

$$z = 0.5\ln\left(\frac{1+r}{1-r}\right)$$

where r is the Pearson correlation coefficient. The inverse Fisher transformation was used to back-transform the z-values to correlation coefficients:

$$r = \frac{\exp(2z)-1}{\exp(2z)+1}$$

In addition, the sampling variance (vi) for each study was calculated as:

$$v_i = \frac{1}{n_i - 3}$$

where n_i is the sample size of study i.

3.3. Meta-Analytic Model

We employed a random-effects meta-analysis to compute the pooled effect sizes for each outcome type (environmental, financial, and innovation performance) and for the overall effect size. The random-effects model accounts for both within-study variance (i.e., sampling error) and between-study variance (i.e., differences in effect sizes across studies). The random-effects model assumes that the true effect size varies across studies, which is a realistic assumption given the heterogeneity observed in this literature.

We employed the Restricted Maximum Likelihood (REML) estimator to calculate the between-study variance (τ^2). We selected the REML estimator as the primary method because it avoids the downward bias often associated with the DerSimonian–Laird esti-

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mator in continuous data, particularly when heterogeneity is substantial. Furthermore, to enhance the reliability of our inference, we constructed 95% confidence intervals using the Hartung–Knapp–Sidik–Jonkman (HK-SJ) adjustment.

The pooled effect size ($\hat{\mu}$) for each outcome domain was computed using the formula:

$$\hat{\mu} = \frac{\sum w_i \cdot \hat{\mu}_i}{\sum w_i}$$

where $\hat{\mu}_i$ is the effect size for study i, and w_i is the weight assigned to study i, which is calculated as:

$$w_i = \frac{1}{v_i + \tau^2}$$

where v_i is the variance of the effect size for study i and τ^2 is the estimated between study variances. This model accounts for the varying precision across studies by assigning higher weights to those with larger sample sizes.

We quantified heterogeneity in effect sizes using Cochran's Q statistics and the I^2 index. The Q statistics test the null hypothesis that all studies share the same effect size; significant values of Q suggest heterogeneity. The I^2 statistic indicates the proportion of total variation in effect sizes that is due to between-study heterogeneity. A value of I^2 above 50% indicates substantial heterogeneity.

3.4. Publication Bias

To assess potential publication bias, we inspected funnel plots for asymmetry and conducted Egger's regression test to detect small-study effects quantitatively. Additionally, we applied the non-parametric trim-and-fill method [12] to impute potentially missing studies and adjust the pooled effect estimates accordingly. This multi-method approach ensures that our conclusions are robust to the file-drawer problem [18] and that the pooled estimates are reliable.

3.5. Moderator Analysis

To examine the potential moderators governing the impact of GI on firm value, we conducted a series of subgroup analyses based on key study characteristics, such as:

1. Innovation Type: GPI vs. GPrI vs. Integrated GI.
2. Study Design: Panel vs. Survey vs. Meta-Analysis.
3. Geography: Studies based in China vs. multi-region vs. other/unclear.
4. Industry Type: High-pollution industries vs. low-pollution industries.

These analyses help uncover whether the effect of GI on performance varies depending on the nature of the innovation or the context in which it occurs.

3.6. Software and Reproducibility

All statistical analyses were conducted in R (version 4.0.3), using the Metafor Package for meta-analytic computations. The data, analysis scripts, and results are available for replication and further analysis. The primary data and R code used to produce the results in this paper, including all effect size calculations, heterogeneity analyses, and publication bias assessments, are available in the Appendix A.

4. Results

4.1. Descriptive Statistics of the Included Studies

The final sample for this meta-analysis comprised 48 empirical studies spanning from 2012 to 2025. These studies collectively examined the relationship between GI (GPI and GPrI) and various performance outcomes, including environmental, financial, and innovation performance. Table 1 presents the descriptive statistics for the studies included in the meta-analysis. The studies cover a wide range of industries and geographical regions, including China, Europe, North America, and multi-country studies.

Table 1. Characteristics of the included studies (k = 48).

Item	Category/Statistic	k	% of Studies
Study design	Survey	23	47.9
Study design	Panel	21	43.8
Study design	Meta-analysis	3	6.2
Study design	Review/ Conceptual	1	2.1
GI type	Integrated GI	35	72.9
GI type	GPI	9	18.8
GI type	GPrI	4	8.3
Outcome domain	Financial	29	60.4
Outcome domain	Environmental	13	27.1
Outcome domain	Innovation	6	12.5
Geographic group (coded)	China	34	70.8
Geographic group (coded)	Other/Unclear	8	16.7
Geographic group (coded)	Multi-country	6	12.5
Publication year	2012–2025	-	-
Sample size (n)	207–29,490	-	-
Effect size r	0.063–0.580	-	-

In the studies included, the sample size ranged from 207 to 29,490, with an average of approximately 4273 and a median of 1698, indicating significant differences in sample size. The evidence base also exhibits meaningful methodological diversity, as shown in Figure 3 for specific classification.

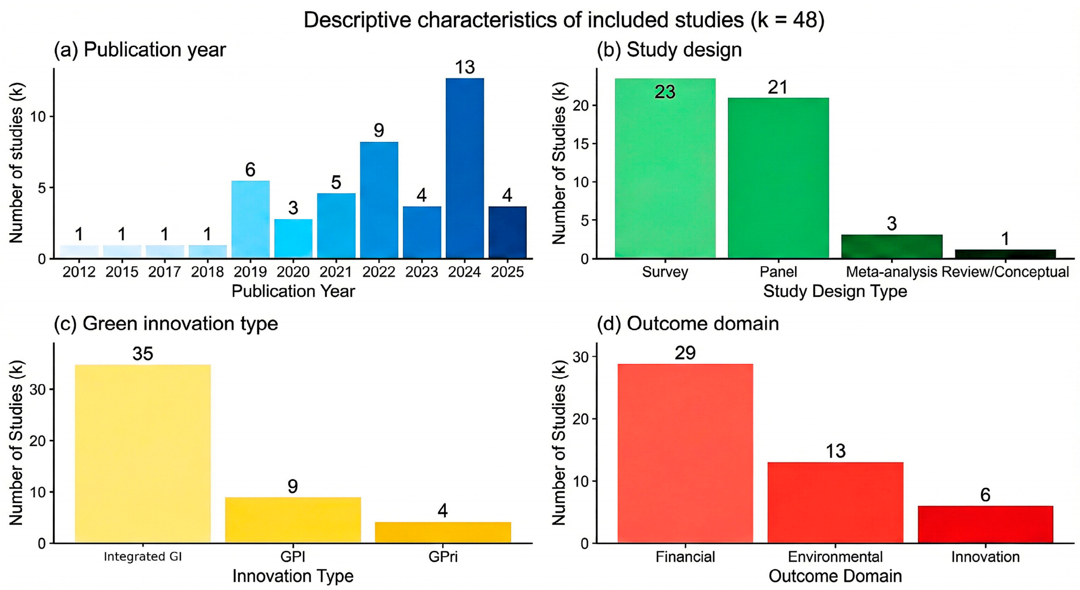

Figure 3. Descriptive characteristics of the included studies (k = 48): (**a**) publication year distribution; (**b**) study design distribution; (**c**) GI type (GPI, GPrI, or Integrated GI); and (**d**) outcome domain (environmental, financial, or innovation performance).

We evaluated the methodological quality of the 48 included studies using a consistent set of criteria. The mean quality score was 6.54 (SD = 1.05), with individual scores ranging from 4 to 8. Approximately 81.3% (39 of 48) of the studies were classified as high-quality (score $\geq$ 6). Sensitivity analyses revealed that excluding lower-quality studies did not significantly alter the pooled effect sizes, thereby confirming the robustness of the meta-analytic conclusions.

4.2. Pooled Effect Sizes by Outcome

Figure 4 illustrates the results of the random-effects meta-analysis using the Hartung–Knapp adjustment. Squares represent study-specific effects (sizes proportional to inverse-variance weights), and the diamond represents the pooled effect with a 95% confidence interval.

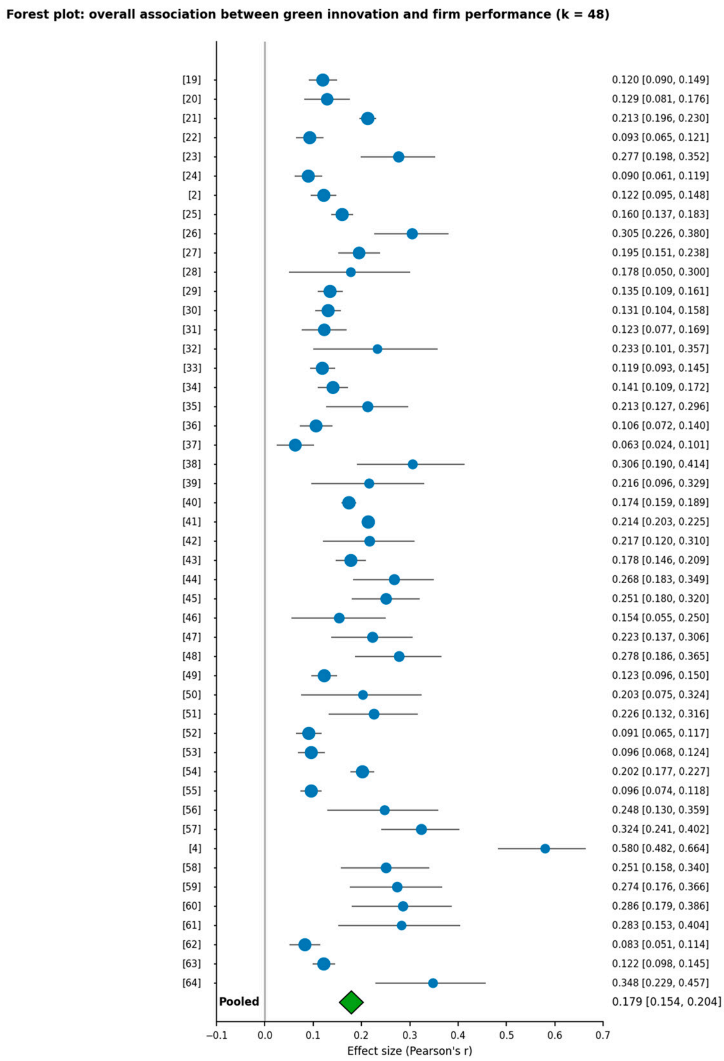

Figure 4. Forest plot for the overall association between GI and firm performance (k = 48; effect size = Pearson's r) [2,4,19–64].

Figure 5 presents the random-effects meta-analytic results with the Hartung–Knapp adjustment; pooled effects are reported with 95% confidence intervals.

Table 2 presents the pooled effect sizes for the three primary outcome domains: environmental performance, financial performance, and innovation performance. The results were derived using the random-effects model, and we also report the 95% confidence intervals for each outcome.

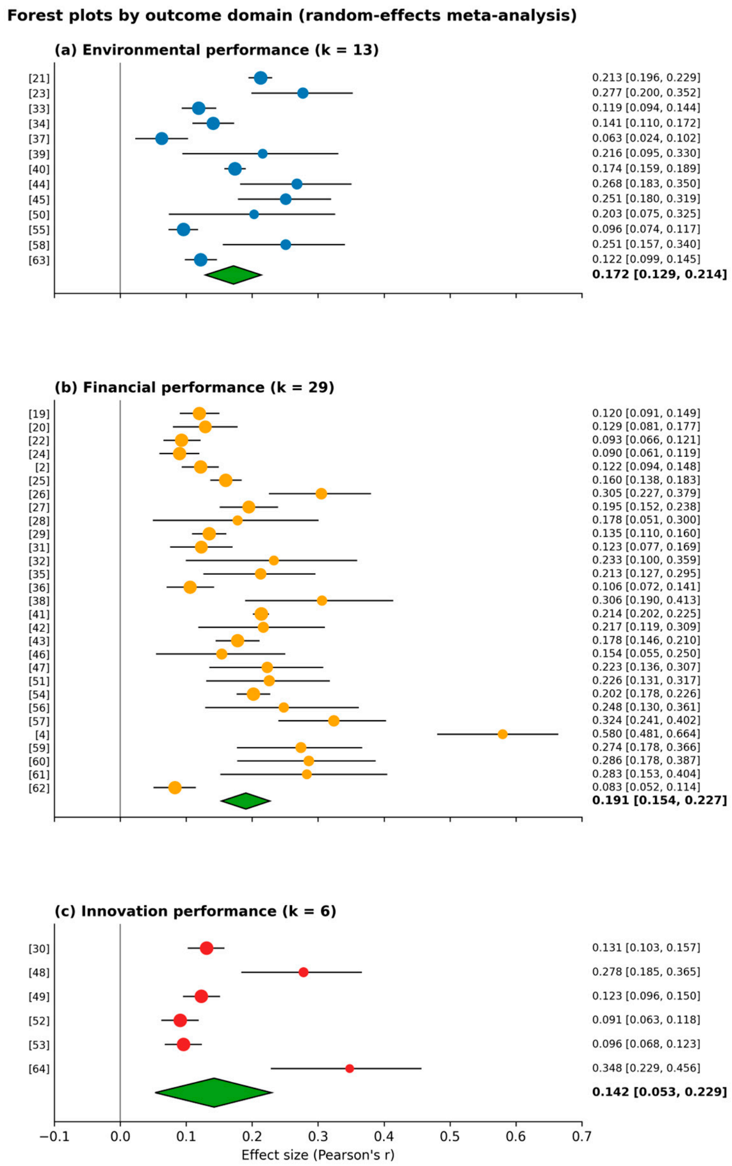

Figure 5. Forest plots by outcome domain: (**a**) environmental performance (k = 13) [21,23,33,34,37,39,40,44,45,50,55,58,63]; (**b**) financial performance (k = 29) [2,4,19,20,22,24–29,31,32,35,36,38,41–43,46,47,51,54,56,57,59–62]; and (**c**) innovation performance (k = 6) [30,48,49,52,53,64].

Table 2. Random-effects meta-analysis pooled effects by outcome domain.

Outcome	*k*	Pooled *r*	95% CI	τ^2	I^2 (%)	*Q* (*df*)	*p* (*Q*)
Overall	48	0.179	[0.154, 0.204]	0.0031	91.2	536.88 (47)	<0.001
Environmental performance	13	0.172	[0.129, 0.214]	0.0028	91.7	144.95 (12)	<0.001
Financial performance	29	0.191	[0.154, 0.227]	0.0037	90.9	308.74 (28)	<0.001
Innovation performance	6	0.143	[0.053, 0.230]	0.0017	84.6	32.37 (5)	<0.001

Notes: Effect sizes are Pearson's r. A Meta-analysis was conducted on Fisher's z and then back-transformed to r. 95% CIs use the Hartung–Knapp adjustment. Q is Cochran's heterogeneity statistic; τ^2 is between-study variance; I^2 is the proportion of total variability due to heterogeneity.

1. Environmental Performance: The aggregation of 13 studies measuring environmental performance yielded a significant, albeit small, positive effect (r = 0.172; see Table 2). This confirms that GI initiatives reliably translate into tangible ecological benefits, such as emission reductions and resource efficiency, rather than serving merely as symbolic compliance.

2. Financial Performance: Regarding financial outcomes (k = 29), the analysis revealed a moderate positive association (r = 0.191), with a slightly stronger magnitude than that for environmental outcomes. This suggests that the returns on GI are multidimensional, driven not only by internal operational efficiencies (e.g., cost savings) but also by external market differentiation and brand equity.
3. Innovation Performance: For innovation performance (k = 6), the pooled estimate indicated a small positive relationship (r = 0.143). This implies that engaging in GI acts as a catalyst for broader absorptive capacities, fostering a spillover effect where environmental problem-solving enhances general new product development and technological learning.
4. Overall Pooled Effect Size: Across the full sample of 48 studies, the overall pooled effect was $r = 0.179$. However, the substantial heterogeneity ($I^2 = 91.2\%$) indicates that the GI-performance nexus is highly context-dependent. This high variability suggests that strategic returns are contingent upon unobserved factors, such as latent institutional nuances and managerial commitment, and underscores the necessity of the moderator analyses detailed below.

4.3. Heterogeneity and Moderator Analysis

1. Heterogeneity (I^2 and Q statistics): The overall heterogeneity, as measured by I^2, was 91.2%, suggesting that more than 90% of the variability in effect sizes is due to between-study differences rather than sampling error. This level of heterogeneity is considered high and indicates that the nexus between GI and corporate success is not uniform across studies. The Q statistic for the overall effect was 536.88, indicating significant heterogeneity and further confirming its presence.
2. Moderator Analysis: To explore sources of heterogeneity, we conducted moderator analyses based on study characteristics, including innovation type (GPI vs. GPrI), study design (panel vs. Survey), geographical region (China vs. multi-country vs. other/unclear), and industry type (high-pollution vs. low-pollution). The results of the moderator analysis are summarized in Table 3.

Table 3. Moderator (subgroup) analyses of the GI–performance association.

Moderator	Category	k	Pooled r	95% CI	I2 (%)
Innovation type	Integrated GI	35	0.353	[0.131, 0.376]	91.7
Innovation type	GPI	9	0.279	[0.181, 0.372]	86.9
Innovation type	GPrI	4	0.245	[0.201, 0.289]	0.0
Innovation type	Between-group test			Q-between = 64.25, df = 2, $p < 0.001$	
Study design	Survey	23	0.266	[0.230, 0.302]	56.5
Study design	Panel	21	0.121	[0.106, 0.135]	80.6
Study design	Meta-analysis	3	0.201	[0.143, 0.257]	90.1
Study design	Between-group test			Q-between = 360.09, df = 2, $p < 0.001$	
Geographic group	China	34	0.155	[0.132, 0.179]	81.5
Geographic group	Other/Unclear	8	0.264	[0.151, 0.370]	89.0
Geographic group	Multi-country	6	0.182	[0.092, 0.269]	96.7
Geographic group	Between-group test			Q-between = 142.96, df = 2, $p < 0.001$	
Industry pollution intensity	High-pollution	20	0.126	[0.110, 0.141]	—
Industry pollution intensity	Low-pollution	28	0.230	[0.205, 0.255]	—
Industry pollution intensity	Between-group test			Q-between = 46.98, df = 1, $p < 0.001$	

Notes: Subgroup pooled effects are random-effects estimates (Hartung–Knapp). A Between-group test reports Q-between from a subgroup-heterogeneity comparison.

As detailed in Table 3 and Figure 6, all examined moderators significantly influenced the heterogeneity of effect sizes. Regarding innovation type, studies employing Integrated GI measures yielded stronger pooled associations than isolated GPI or GPrI, and the between-group heterogeneity test (Q-between) confirmed that these subgroup differences were statistically significant ($p < 0.001$).

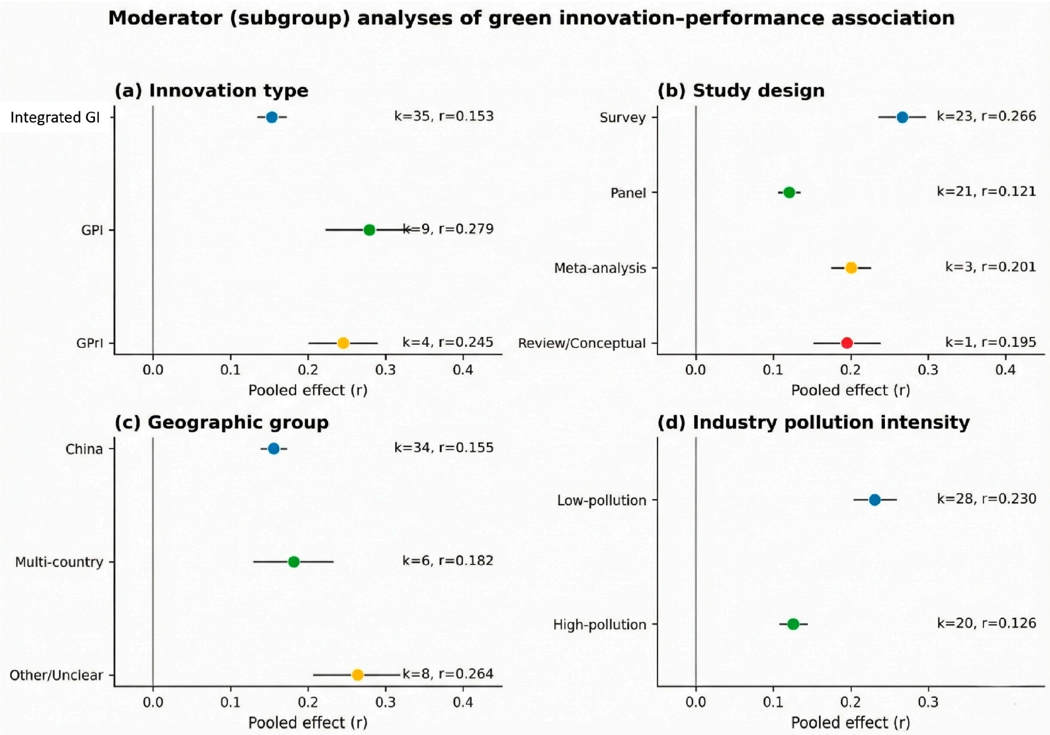

Figure 6. Subgroup (moderator) analyses of the GI-performance association by (**a**) innovation type (GPI, GPrI, Integrated GI), (**b**) study design (panel, survey, meta-analysis), (**c**) geographic group (China, multi-country, other/unclear), and (**d**) industry type (high-pollution vs. low-pollution). Pooled effects are random-effects estimates with 95% confidence intervals; p-values refer to between-group heterogeneity tests.

Notably, the Hartung–Knapp procedure yields more conservative interval estimates under substantial heterogeneity, which explains the relatively wide confidence interval for the Integrated GI subgroup.

Methodologically, survey-based designs reported consistently higher effect sizes compared to panel data studies (r_{survey} = 0.266 vs. r_{panel} = 0.121). Geographically, studies originating in China reported more conservative estimates (r = 0.155) than multi-country or other regional samples.

Finally, industry context mattered substantially: GI exhibited a stronger correlation with performance in low-pollution industries (r = 0.230) than in high-pollution sectors (r = 0.126), suggesting that the strategic value of green initiatives varies by environmental intensity.

Notably, heterogeneity was substantial in most subgroups (often $I^2 > 80\%$), underscoring that these pooled estimates reflect average associations amid considerable between-study variability and should be interpreted as evidence of moderation in correlational strength rather than as causal effects.

We further examined the influence of individual studies on heterogeneity and the pooled effect using influence diagnostics (Baujat plot and leave-one-out analysis), as shown in Figure 7.

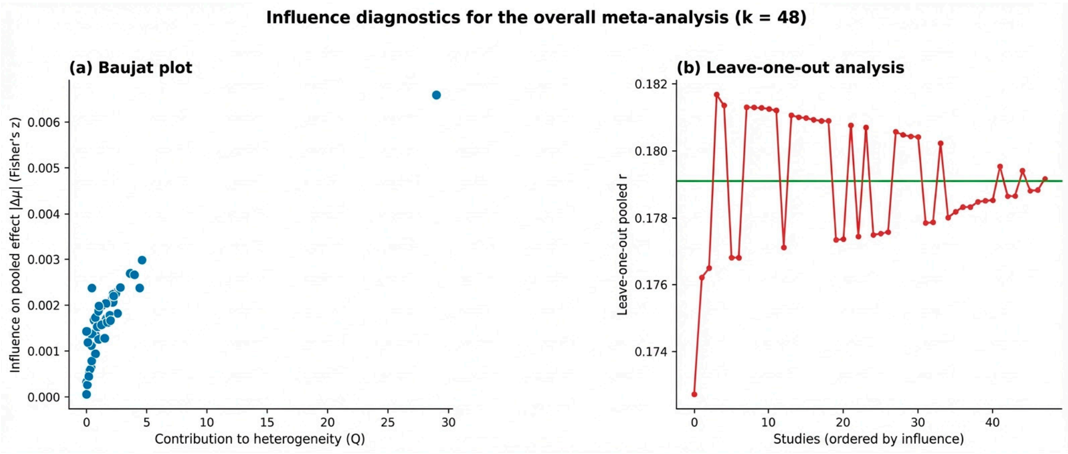

Figure 7. Influence diagnostics for the overall meta-analysis (k = 48). (**a**) Baujat plot highlighting studies contributing most to heterogeneity and influence on the pooled effect (blue dots indicate individual studies); (**b**) leave-one-out analysis showing the pooled effect after removing each study in turn (red line with dots), with the overall pooled effect shown as a green horizontal line.

4.4. Publication Bias Assessment

We used Egger's regression test to assess potential small-study effects shown in Table 4. For the overall dataset, the intercept was not statistically significant (intercept = 0.924, p = 0.275), indicating no evidence of systematic publication bias across the full sample. Similarly, the environmental (p = 0.680) and financial (p = 0.522) domains showed no signs of asymmetry. However, subgroup diagnostics revealed heterogeneity in bias risks. Specifically, the innovation performance domain exhibited a significant Egger's intercept (intercept = 4.829, p = 0.016), suggesting that smaller studies with negative or null results may be underrepresented in this specific sub-field.

Table 4. Publication bias diagnostics (Egger's regression).

Outcome	Egger Intercept	SE	t (df)	*p*	Trim-and-Fill Imputed k0	Adjusted Pooled r
Overall	0.924	0.836	1.11 (46)	0.275	0	0.179
Environmental	0.757	1.787	0.42 (11)	0.680	0	0.172
Financial	0.659	1.015	0.65 (27)	0.522	0	0.191
Innovation	4.829	1.199	4.03 (4)	0.016	1	0.135

Shown in Tables 5 and 6, Figures 8 and 9, the trim-and-fill analysis further corroborated these nuances. For the overall dataset and the environmental/financial sub-samples, no missing studies were imputed (k0 = 0), leaving the pooled estimates unchanged. For the innovation performance domain, the procedure imputed one potentially missing study on the left side of the funnel plot. This adjustment resulted in a marginal decrease in the pooled correlation from r = 0.143 to r = 0.135. Although the effect remains positive and significant, this slight attenuation suggests that the magnitude of the GI-innovation relationship reported in the literature may be slightly overestimated.

Table 5. Sensitivity analysis (leave-one-out) for the overall meta-analysis.

Metric	Value
Pooled effect (all studies)	r = 0.179
Leave-one-out pooled effect (minimum)	r = 0.173 (omit: Vietnam market demand → GPI → performance)
Leave-one-out pooled effect (maximum)	r = 0.182 (omit: Technology Innovation)
Maximum absolute change ∣Δr∣	0.006 (omit: Vietnam market demand → GPI → performance)

Notes: The leave-one-out analysis recalculates the pooled effect after omitting each study in turn to evaluate robustness.

Table 6. Top studies by absolute influence on the pooled effect (largest |Δr|).

Study ID	Year	Outcome	Innovation Type	n	Extracted r	Δr (Leave-One-Out)
Vietnam market demand → GPI → Performance	2012	Financial	GPI	208	0.580	−0.006
Stakeholder pressure → GI → Performance (SMEs)	2021	Financial	Integrated GI	472	0.324	−0.003
Green innovation and performance	2019	Financial	GPI	536	0.305	−0.003
Technology Innovation	2025	Environmental	Integrated GI	2579	0.063	+0.003
Depth vs. breadth of ecological innovation assets	2025	Financial	Integrated GI	3817	0.083	+0.002

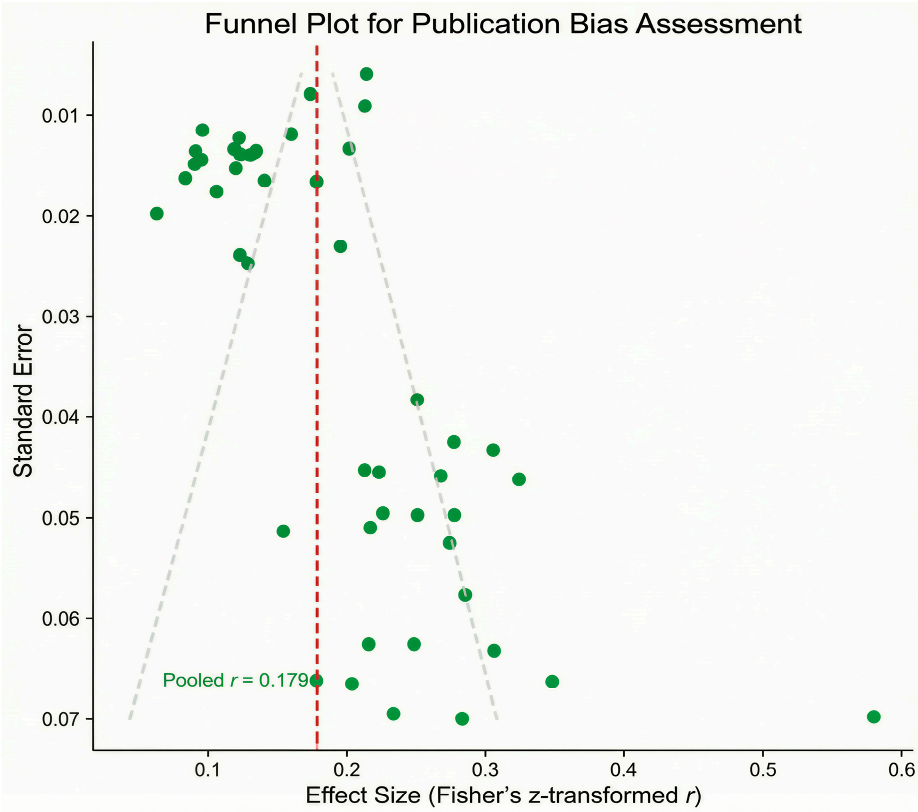

Figure 8. Funnel plot for publication bias assessment of the overall meta-analysis. Effect sizes are plotted against their standard errors with pseudo-95% confidence limits (green dots indicate individual studies; red dashed line indicates the pooled effect; grey dashed lines show pseudo-95% limits).

Egger's regression test results are reported in Figure 8 (intercept = 0.924, p = 0.275).

The trim-and-fill analysis (Figure 9) imputed no missing studies for the overall dataset nor for the environmental and financial sub-samples ($k0$ = 0), leaving the pooled estimates unchanged. This indicates that our core findings are robust to potential publication bias. However, for the innovation performance domain, the procedure imputed one potentially missing study, resulting in a slight adjustment of the pooled effect from r = 0.143 to r = 0.135. Coupled with the significant Egger's test result (p = 0.016), this suggests that findings regarding innovation outcomes should be interpreted with appropriate caution due to the smaller evidence base (k = 6).

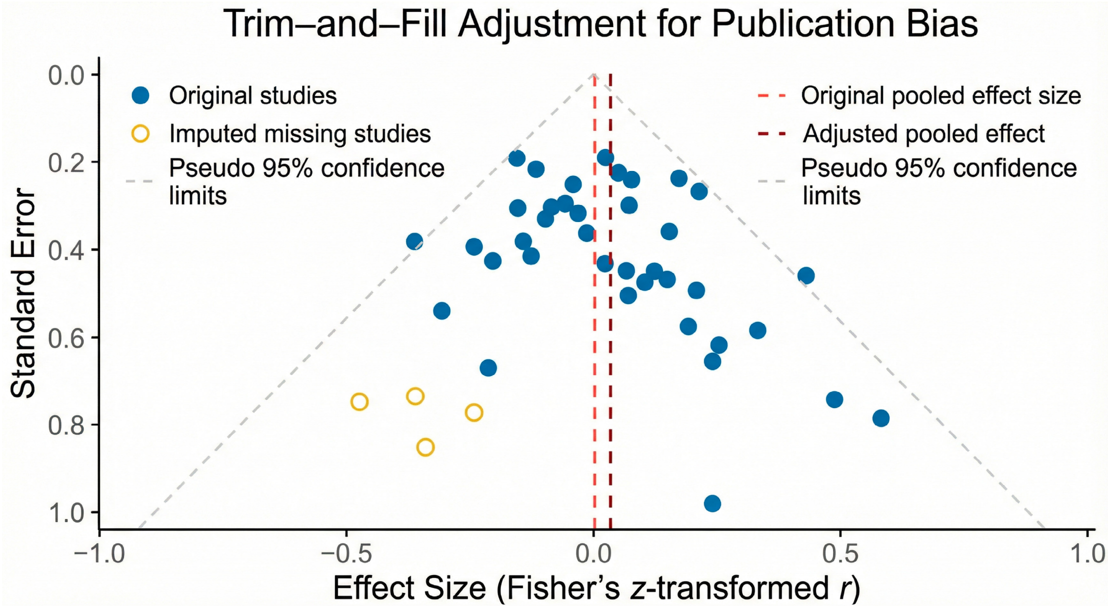

Figure 9. Trim-and-fill adjustment for potential publication bias.

4.5. Summary of Results

In summary, the meta-analysis reveals that GI has a small-to-moderate positive effect on firm performance across environmental, financial, and innovation outcomes. While substantial heterogeneity exists across studies, several moderators, including innovation type, study design, geography, and industry, help explain the variability in effect sizes. The trim-and-fill analysis suggests that publication bias does not significantly influence the results, and the Egger's test confirms the absence of small-study effects. These findings contribute to the growing body of literature on GI by providing robust pooled estimates and identifying key factors that influence the effectiveness of GI in improving firm performance.

However, a cautionary note is warranted: given that the majority of synthesized studies relied on survey data, the findings regarding innovation performance are based on a limited number of effect sizes (k = 6) and lack verification from objective indicators (e.g., patent grants). Thus, these specific estimates should be interpreted as indicative rather than definitive.

Overall, publication-bias diagnostics indicated limited evidence of small-study effects for the full dataset and for financial/environmental outcomes; however, innovation-performance estimates were less robust, as indicated by Egger's test and trim-and-fill adjustment, and should therefore be interpreted conservatively.

5. Discussion

5.1. Theoretical Implications

This study establishes a robust baseline for the magnitude of returns on GI. The overall pooled correlation (r = 0.179) suggests a positive but moderate relationship. According to established benchmarks in management research [65], where the median effect size for organizational performance outcomes is typically around $r = 0.16$, our finding indicates that GI is a meaningful driver of firm value, comparable to other strategic determinants.

However, the magnitude also suggests that GI is not a silver bullet; rather, its impact on performance is highly contingent on complementary capabilities and external conditions, as evidenced by the substantial heterogeneity ($I^2 = 91.2\%$) in our model. Our findings extend extant theory in four primary dimensions:

5.1.1. Revisiting NRBV: From Universal Benefit to Contextual Fit

While our results generally support the NRBV [15], the high heterogeneity observed challenges the assumption of a universal Green Bonus [66]. Instead, our findings support a contingent NRBV perspective. The significant variation in effect sizes across industries suggests that the strategic value of green resources is path-dependent [14].

Specifically, in low-pollution industries, GI appears to act as a differentiation capability (pooled $r = 0.230$). In these sectors, environmental features are often voluntary and visible, allowing firms to command premium pricing and build unique brand equity. Conversely, in high-pollution sectors, GI often functions merely as a license to operate driven by coercive isomorphism (pooled $r = 0.126$). In such contexts, widespread regulatory mandates lead to industry-wide standardization, eroding the potential for differentiation and reducing the marginal financial return on green investments.

5.1.2. From Ordinary to Dynamic: The Role of Asset Orchestration

Crucially, our moderator analysis reveals that the mechanism linking GI to performance is not monolithic but depends on the nature of capability deployment. The strikingly higher pooled effect size for Integrated GI (r = 0.353) compared to isolated GPI (r = 0.279) or GPrI (r = 0.245) offers a compelling theoretical insight through the lens of Dynamic Capabilities [67].

We propose that isolated GI often function as ordinary capabilities—technical efficiencies or product updates aimed at operational effectiveness. While beneficial, they do not fundamentally alter the firm's competitive logic [68]. In contrast, the simultaneous implementation of product and process innovations (Integrated GI) reflects a higher-order Dynamic Capability known as Asset Orchestration [69].

This orchestration requires firms to actively realign their internal production routines (process) with external market value propositions (product). The statistically superior performance of the Integrated GI group suggests that GI's competitive advantage stems not merely from possessing green resources, but from the configurational fit achieved by recombining these assets. Thus, heterogeneity in effect sizes across studies is partially explained by whether firms are deploying GI as a piecemeal technical fix or as a systemic strategic reconfiguration.

5.1.3. Complementarity Between GPI and GPrI

Our analysis highlights the strategic value of Integrated GI. While many studies have treated GPI and GPrI as separate constructs, our results suggest that when these innovations are implemented in tandem, they generate synergetic benefits. This complementarity is particularly evident in industries with high environmental impacts, where both types of innovation, product and process, are crucial for achieving both environmental and financial improvements [2,13]. Theoretically, this points to a synergy premium. From the NRBV, product and process innovations are complementary assets. GPrI (e.g., energy efficiency) often subsidizes the higher costs associated with developing green products, while green products create the market demand that justifies process upgrades. Therefore, firms adopting a holistic green strategy likely reap super-additive benefits that exceed the sum of independent initiatives.

5.2. Managerial Implications

5.2.1. Strategic Investment in GI

For managers, the findings from this meta-analysis provide valuable insights into the strategic benefits of GI. GI, both in products and processes, offers firms the potential to improve environmental performance, enhance financial returns, and foster broader innovation capabilities. However, the magnitude of these benefits depends on the type of innovation and the firm's context. Managers should carefully consider the type of GI that best aligns with their firm's strategic objectives. For instance, firms in high-pollution industries may benefit more immediately from GPrI, leading to cost savings and operational efficiency (e.g., energy reductions, waste minimization). In contrast, firms seeking to differentiate their offerings in the marketplace may gain more from GPI (e.g., eco-friendly products, green certifications).

5.2.2. Policymaking and Regulatory Environment

The role of policy and regulation in driving GI is also a crucial consideration. Our findings suggest that stringent regulatory environments may increase the likelihood that firms adopt GI; however, the magnitude of performance remains context-dependent. In our moderator analysis, China-based samples yielded more conservative pooled estimates than other regions, underscoring that regulatory stringency does not mechanically translate into larger observed effect sizes. Policymakers can leverage these findings to design policies that incentivize GI, such as offering tax credits, subsidies, or green certification programs. Additionally, government support for R&D in green technologies can help firms overcome the initial cost barriers to GI, particularly for SMEs. Firms in regions with weaker environmental regulations may require additional incentives to adopt GI, such as market-based solutions (e.g., carbon trading schemes) or consumer pressure to embrace more sustainable practices.

5.2.3. Implications for SMEs

Small and medium-sized enterprises (SMEs), which often face resource constraints, may find it challenging to implement GI. Our findings indicate that GPrI, which tends to yield faster cost savings, may be more beneficial for SMEs in the short term than GPI.

However, SMEs should not overlook the long-term strategic benefits of GPI, such as market differentiation and access to eco-conscious consumers. Policymakers and industry leaders can support SMEs by providing access to financing, partnerships, and knowledge sharing to facilitate the adoption of GI.

5.3. Limitations and Future Research Directions

5.3.1. Measurement Heterogeneity

A key limitation of this study is the heterogeneity in the measurement of GI and performance outcomes across studies. While we classified studies into GPI and GPrI categories, the specific measurement approaches varied significantly (e.g., self-reported surveys vs. objective metrics). Future research should develop standardized metrics for GI and performance outcomes to facilitate more direct comparisons across studies.

Additionally, more detailed studies that examine the specific dimensions of GI (e.g., technological vs. organizational innovations) would provide further insights into the mechanisms driving performance outcomes.

Third, readers should interpret the findings regarding innovation performance with appropriate caution. While our overall meta-analysis (k = 48) demonstrates robustness to publication bias ($p = 0.275$), the innovation subsample (k = 6) exhibited signs of small-study effects (Egger's test $p = 0.016$). Although the trim-and-fill adjustment confirmed that the core relationship holds (r adj = 0.135), the statistical asymmetry implies a potential file-drawer problem specific to this outcome domain, likely due to the smaller evidence base. Future research utilizing objective patent metrics is necessary to verify these survey-dominant findings.

Moreover, the predominance of survey-based designs in our sample introduces the risk of Social Desirability Bias (SDB) [70], in which respondents may overstate the efficacy

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of green initiatives to align with normative expectations. To rigorously validate the green premium, future research must pivot toward objective, verifiable indicators.

Specifically, we urge scholars to employ patent-quality metrics (e.g., green patent citations to proxy technical quality, rather than mere counts) and audited R&D expenditure data. Such hard metrics are indispensable for disentangling whether performance gains stem from genuine substantive technical value (best captured by patent data) or merely from the symbolic legitimacy of "going green" (often captured by perceptual measures). Triangulating these data sources will allow the field to move beyond correlation to identify the true drivers of value creation [18].

5.3.2. Longitudinal and Causal Research

Although this meta-analysis provides valuable aggregate insights, it is limited by the cross-sectional nature of most of the included studies. Longitudinal studies are needed to examine the causal mechanisms linking GI to performance over time. Future research should explore the temporal dynamics of GI adoption and its impact on firm performance, as well as the role of organizational capabilities, such as dynamic capabilities and absorptive capacity, in facilitating GI implementation.

It is important to acknowledge the geographic skew of our sample, with approximately 70% of studies originating from China. This concentration reflects the specific institutional context of an emerging economy undergoing rapid, state-led ecological transition. The distinct pattern of GI-environment associations observed in this context may be partially driven by government subsidies and legitimacy pressures unique to the authoritarian environmentalism model [71]. Consequently, scholars should exercise caution when generalizing these findings to liberal market economies (e.g., the US or UK), where market forces rather than regulatory mandates may be the primary drivers of GI outcomes.

5.3.3. Exploring the Role of Stakeholders

Another promising avenue for future research is examining the role of external stakeholders, such as consumers, investors, and regulatory bodies, in driving the adoption of GI. Research could investigate how consumer preferences for sustainability and the pressure from investors or regulatory bodies influence firms' GI strategies [72]. Additionally, understanding how firms' supply chain partners impact the implementation and success of GI would provide valuable insights into the broader ecosystem in which GI occurs [73].

5.3.4. Unobserved Institutional and Organizational Heterogeneity

Finally, despite controlling for industry, geography, and study design, significant residual heterogeneity remains in our model (I^2 = 91.2%). We interpret this as evidence that latent institutional and organizational factors not captured in primary studies likely moderate the efficacy of GI.

Corporate governance structures, specifically the distinction between State-Owned Enterprises (SOEs) and private firms, may fundamentally alter the strategic logic of GI. SOEs often engage in green initiatives to satisfy political mandates or legitimacy requirements, which may yield different financial returns than those of private firms, driven primarily by market efficiency and cost–benefit calculations [74,75]. Our current dataset lacked sufficient granularity to test this ownership effect as a moderator.

National cultural dimensions, such as collectivism versus individualism, may influence stakeholders' valuation of GI [76]. In collectivist cultures, firms adopting green practices might garner stronger reputational rewards and stakeholder support because of a greater societal emphasis on communal welfare. Conversely, in highly individualistic or short-term-oriented cultures, the market may penalize the upfront costs of GI more heavily [77].

We strongly recommend that future primary studies explicitly report governance attributes and that future meta-analyses incorporate cross-country cultural indices (e.g., Hofstede's dimensions) to disentangle these unobserved sources of variability [78].

6. Conclusions

6.1. Key Findings

This meta-analysis integrates findings from 48 empirical studies to provide a comprehensive understanding of the relationship between GI (GPI, GPrI, and Integrated GI) and firm performance. Our results indicate a small-to-moderate positive relationship between GI and three key performance outcomes: environmental, financial, and innovation performance. These findings contribute to the growing literature on GI by providing robust, pooled effect sizes and by identifying several critical factors that explain heterogeneity in the GI-performance nexus. Key findings include:

1. Environmental Performance: GI has a positive, albeit small, effect on environmental performance (r = 0.172), indicating that firms adopting GI tend to reduce their environmental impact. This result aligns with the broader sustainability literature, supporting the idea that GI is crucial for achieving environmental goals.
2. Financial Performance: We found a moderate positive relationship (r = 0.191) between GI and financial performance. This suggests that GI, especially in product design and process improvements, can provide financial benefits to firms through cost savings, enhanced market differentiation, and improved customer loyalty.
3. Innovation Performance: GI also contributes to innovation performance (r = 0.143), though the effect is smaller. These results indicate that firms engaged in GI not only improve their environmental and financial outcomes but also enhance their technological and product development capabilities.
4. Moderating Effects: Our analysis revealed that several moderators, including innovation type (GPI vs. GPrI), study design, geographical region, and industry type, explain significant portions of the heterogeneity in the GI-performance relationship. For example, studies conducted in low-pollution industries reported larger pooled associations than those in high-pollution industries, whereas China-based samples tended to yield more conservative pooled estimates than multi-country or other-region studies, underscoring the context dependence of GI–performance relationships.
5. Publication Bias: We assessed publication bias using a triangulation of methods. The results indicated minimal evidence of bias for the overall dataset and financial/environmental outcomes. However, bias was detected in the innovation performance domain, necessitating a more conservative interpretation of its effect size than for other outcomes.

6.2. Contributions to Theory

This study makes several important contributions to the theoretical understanding of GI. First, it builds on the NRBV and Dynamic Capabilities framework by providing empirical evidence that GI is associated with modest competitive benefits on average, contingent on complementary capabilities and contextual conditions. By adopting GPI and GPrI, firms not only improve their environmental performance but also enhance their financial and innovation capabilities. This finding underscores the importance of integrating environmental considerations into a firm's strategic orientation to achieve long-term sustainability.

Moreover, our analysis supports the notion of complementarity between GPI and GPrI. While both types of innovation contribute positively to firm performance, their combined implementation appears to yield stronger overall benefits. This highlights the need for firms to adopt a holistic approach to GI, where product and process innovations are not treated as independent but as interconnected strategies that amplify one another's effects.

Finally, our findings contribute to the broader literature on innovation and sustainability by highlighting how GI can foster broader innovation capabilities within firms. This extends the work of previous studies [16,79] that suggested that GI can act as a catalyst for broader technological and product development processes.

6.3. Practical Implications

The practical implications of this study are notable but context-dependent for managers and policymakers, given the small-to-moderate effect sizes (r = 0.143–0.191). While statistically significant, these effects suggest incremental benefits from GI, such as steady improvements in environmental performance, financial outcomes, and innovation capacity, rather than transformative impacts. The strategic value of GI is thus contingent on several factors, requiring tailored approaches to realize modest returns:

1. Innovation Type: Managers should view GPI and GPrI as complementary strategies, rather than independent ones, to leverage potential synergies. While GPrI may offer more immediate, albeit modest, financial benefits through operational efficiencies (e.g., cost reductions and process efficiencies), GPI provides longer-term advantages in market differentiation and customer loyalty. Firms in high-pollution industries could prioritize GPrI for quicker, incremental gains, whereas those seeking sustainability leadership might invest in Integrated GI, though returns remain context-specific [80].
2. Policy and Regulatory Environment: Policymakers can support GI adoption by fostering enabling regulatory frameworks that incentivize sustainable practices, potentially yielding small but cumulative benefits. This could involve tax incentives, green subsidies, or environmental certifications to modestly enhance firm competitiveness [81]. Additionally, stricter regulations may encourage incremental innovation in response to pressures [5,6], although the magnitude of these gains remains context-dependent and may vary across institutional settings; accordingly, the current pooled evidence, dominated by China-based studies, should not be generalized to liberal market economies without additional cross-country validation.
3. SMEs and Resource Constraints: Small and medium-sized enterprises (SMEs), often constrained by resources and expertise, may derive modest benefits from GPrI, which offers quicker returns through cost savings. However, it is necessary to integrate dynamic capabilities to cope with heterogeneity. Policymakers and industry leaders can facilitate this by providing access to green technologies, financing, and training programs, helping SMEs achieve incremental sustainability gains without overcommitting limited resources [82].

6.4. Limitations and Directions for Future Research

While this study provides valuable insights, it is not without limitations.

As with any meta-analysis, the findings are constrained by the quality and heterogeneity of the included studies. Although we applied rigorous inclusion criteria and used advanced statistical methods to account for heterogeneity, some variability in effect sizes remains unexplained. Future research should standardize the measurement of GI and performance outcomes to enhance comparability across studies [83].

The majority of the studies included in this meta-analysis are cross-sectional, limiting our ability to infer causal relationships between GI and firm performance. Longitudinal studies that track the impact of GI over time are needed to better understand its long-term effects on firm outcomes.

Future research should explore the role of external factors, such as consumer pressure, stakeholder demands, and supply chain dynamics, in driving the adoption of GI. Understanding how external stakeholders influence firms' GI strategies could provide further insights into the drivers of sustainable innovation [84].

Finally, there is a need for more research on the role of organizational capabilities in enabling the successful implementation of GI. Research on absorptive capacity and dynamic capabilities could help explain why some firms are more successful than others in leveraging GI to improve their performance [85,86].

Overall,, this meta-analysis provides robust evidence of the positive relationship between GI and firm performance across environmental, financial, and innovation domains. While the magnitude of these effects varies across studies, GI, whether in the form of product or process innovation, offers significant benefits to firms. However, the effectiveness of these innovations depends on the firm's context, including industry type, geographic location, and regulatory environment. By integrating GPI and GPrI, firms may achieve incremental yet meaningful improvements in environmental and financial outcomes, although the magnitude of these gains remains context dependent. Accordingly, GI should be framed as a strategic lever whose benefits are realized through complementary capabilities and supportive institutional conditions, rather than as a guarantee of superior performance. Future research should continue to explore the role of external factors and organizational capabilities in driving the success of GI initiatives.

Author Contributions: F.Z. and L.H. conceptualized the study. F.Z. and M.L. developed the methodology and validated the study. F.Z. and X.X. completed the data curation and conducted the formal analysis. F.Z. and L.H. led the investigation and coordinated resources, wrote the original draft and supervised the study. All authors have read and agreed to the published version of the manuscript.

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

Appendix A

Appendix A.1

Table A1. Included studies and extracted effect sizes (k = 48).

ID	Citation	Title	Y-Type	Design	Country/Region	*r*	*n*	*t*	*β*	Fisher *z*	*vi*	se *z*
1	[19]	Does green innovation promote financial performance of Chinese listed companies?	fin	Panel	China	0.120	4314	7.940	0.120	0.121	0.000	0.015
2	[20]	Green process innovation, green product innovation and its economic performance transmission	fin	Panel	China	0.129	1640	5.263	0.129	0.130	0.001	0.025
3	[21]	Green innovation for a greener future: A meta-analysis of the impact on performance	env	Meta-analysis	Multi	0.213	12,334	24.227	0.213	0.216	0.000	0.009
4	[22]	The effect of green innovation on corporate financial performance: Does quality matter?	fin	Panel	China	0.093	4788	6.482	0.093	0.094	0.000	0.014

Table A1. *Cont.*

ID	Citation	Title	Y-Type	Design	Country/Region	*r*	*n*	*t*	*β*	Fisher *z*	*vi*	se *z*
5	[23]	Exploring a pathway to carbon neutrality via reinforcing environmental performance through green process innovation, environmental orientation and green competitive advantage	env	Survey	China	0.277	557	6.799	0.277	0.285	0.002	0.042
6	[24]	Green innovation and firm performance: Evidence from listed companies in China	fin	Panel	China	0.090	4554	6.114	0.090	0.090	0.000	0.015
7	[2]	Green process innovation, green product innovation, and corporate financial performance: A content analysis method	fin	Panel	China	0.122	5290	8.924	0.122	0.122	0.000	0.014
8	[25]	Green innovation, firm performance, and risk mitigation: evidence from the USA	fin	Panel	China	0.160	7099	13.673	0.160	0.162	0.000	0.012
9	[26]	Green innovation and performance: Moderation analyses from Thailand	fin	Survey	Thailand	0.305	536	7.411	0.305	0.315	0.002	0.043
10	[27]	Boosting green innovation on corporate performance: Managerial environmental concern's moderating role	fin	Review/Concep-tual	Multi	0.195	1902	8.675	0.195	0.198	0.001	0.023
11	[28]	Green product innovation and firm performance: Assessing the moderating role of business model	fin	Survey	China	0.178	231	2.737	0.178	0.180	0.004	0.066
12	[29]	The impact of green innovation on corporate performance: Substantive vs strategic GI	fin	Panel	China	0.135	5502	10.081	0.135	0.136	0.000	0.013
13	[30]	Financial performance feedback, institutional ownership and green innovation: evidence from China	inn	Panel	China	0.131	5187	9.493	0.131	0.131	0.000	0.014
14	[31]	Interaction of corporate social responsibility reporting at the crossroads of green innovation performance and firm performance: the moderating role of the enterprise life stage	fin	Panel	China	0.123	1757	5.199	0.123	0.124	0.001	0.024
15	[32]	Eco-innovation and its role for performance improvement among Chinese small and medium-sized manufacturing enterprises	fin	Survey	China	0.233	210	3.463	0.233	0.238	0.005	0.070
16	[33]	Green management, firm innovations, and environmental turbulence	env	Panel	China	0.119	5621	8.993	0.119	0.120	0.000	0.013
17	[34]	Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation	env	Panel	China	0.141	3713	8.667	0.141	0.142	0.000	0.016
18	[35]	Green innovation and firm performance: the mediating role of sustainability in the automotive industry	fin	Survey	Mexico	0.213	491	4.816	0.213	0.216	0.002	0.045
19	[36]	Green innovation and corporate financial performance: Insights from operating risks	fin	Panel	China	0.106	3261	6.101	0.106	0.107	0.000	0.018
20	[37]	Green technology innovation, ESG ratings and corporate sustainable performance: Empirical evidence from listed semiconductor companies in China	env	Panel	China	0.063	2579	3.203	0.063	0.063	0.000	0.020
21	[38]	The penetration of green innovation on firm performance: Effects of absorptive capacity and managerial environmental concern	fin	Survey	China	0.306	253	5.092	0.306	0.316	0.004	0.063
22	[39]	Environmental ethics, green innovation, and sustainable performance: Exploring the role of environmental leadership and environmental strategy	env	Survey	China	0.216	258	3.531	0.216	0.219	0.004	0.063
23	[40]	Eco-innovation and SMEs' sustainable performance: a meta-analysis	env	Meta-analysis	SMEs	0.174	16,447	22.653	0.174	0.176	0.000	0.008
24	[41]	A systematic literature review and bibliometric analysis of eco-innovation on financial performance: Identifying barriers and drivers	fin	Meta-analysis	Multi	0.214	29,490	37.642	0.214	0.217	0.000	0.006
25	[42]	Linking green customer and supplier integration with green innovation performance: The role of internal integration	fin	Survey	China	0.217	388	4.360	0.217	0.220	0.003	0.051
26	[43]	The relationship between green product innovation and accounting-based financial performance: insights from non-linear modeling	fin	Panel	East Asia	0.178	3656	10.943	0.178	0.180	0.000	0.017
27	[44]	Green managerial practices and green performance: a serial mediation model	env	Survey	China	0.268	479	6.071	0.268	0.275	0.002	0.046
28	[45]	The mediating effect of green innovation on the relationship between green supply chain management and environmental performance	env	Survey	China	0.251	688	6.782	0.251	0.256	0.001	0.038
29	[46]	How environmental leadership shapes green innovation performance: A resource-based view	fin	Survey	China	0.154	383	3.046	0.154	0.155	0.003	0.051
30	[47]	Green core competencies, green process innovation, and firm performance: The moderating role of sustainability consciousness, a mixed method study on golf hotels	fin	Survey	Turkey	0.223	486	5.034	0.223	0.227	0.002	0.046

Table A1. *Cont.*

ID	Citation	Title	Y-Type	Design	Country/Region	*r*	*n*	*t*	*β*	Fisher *z*	*vi*	se *z*
31	[48]	Exploring institutional pressures, firm green slack, green product innovation and green new product success: Evidence from Taiwan's high-tech industries	inn	Survey	China	0.278	408	5.822	0.278	0.285	0.002	0.050
32	[49]	Corporate digitalization and green innovation: Evidence from textual analysis	inn	Panel	China	0.123	5235	8.995	0.123	0.124	0.000	0.014
33	[50]	Green innovation and business sustainability: New evidence from energy intensive industry in China	env	Survey	China	0.203	229	3.131	0.203	0.206	0.004	0.067
34	[51]	Green process innovation and innovation benefit: Mediating effect of image	fin	Survey	China	0.226	411	4.694	0.226	0.230	0.002	0.050
35	[52]	Corporate ESG Performance, Green Innovation, and Green New Quality Productivity: Evidence from China	inn	Panel	China	0.091	5465	6.727	0.091	0.091	0.000	0.014
36	[53]	Assessing the impact of green tax reforms on corporate environmental performance and economic growth: do green reforms promote the environmental performance in heavily polluted enterprises?	inn	Panel	China	0.096	4830	6.683	0.096	0.096	0.000	0.014
37	[54]	The virtuous circle between green product innovation and performance: The role of financial constraint and corporate brand	fin	Panel	China	0.202	5735	15.603	0.202	0.205	0.000	0.013
38	[55]	Green innovation and firms' financial and environmental performance: The roles of pollution prevention versus control	env	Panel	Multi	0.096	7697	8.440	0.096	0.096	0.000	0.011
39	[56]	Green process innovation and financial performance: The role of green social capital and customers' tacit green needs	fin	Survey	China	0.248	258	4.103	0.248	0.254	0.004	0.063
40	[4]	Stakeholder pressure, green innovation, and performance in small and medium-sized enterprises: The role of green dynamic capabilities	fin	Survey	Multi	0.324	472	7.430	0.324	0.336	0.002	0.046
41	[57]	Market demand, green product innovation, and firm performance: Evidence from Vietnam motorcycle industry	fin	Survey	Vietnam	0.580	208	10.219	0.580	0.662	0.005	0.070
42	[58]	Positive influences of green innovation on company performance	env	Survey	Turkey	0.251	408	5.221	0.251	0.256	0.002	0.050
43	[59]	Profiting from green innovation: The moderating effect of competitive strategy	fin	Survey	China	0.274	366	5.445	0.274	0.282	0.003	0.052
44	[60]	Environmental collaboration, responsible innovation, and firm performance: The moderating role of stakeholder pressure	fin	Survey	Pakistan	0.286	304	5.177	0.286	0.294	0.003	0.058
45	[61]	Green intellectual capital and ambidextrous green innovation: The impact on environmental performance	fin	Survey	China	0.283	207	4.228	0.283	0.291	0.005	0.070
46	[62]	Accumulate or Diversify Ecological Innovation Assets? The Effect of Ecological Innovation Asset Depth and Breadth on Firm Financial Performance	fin	Panel	Multi	0.083	3817	5.160	0.083	0.083	0.000	0.016
47	[63]	ESG ratings and green innovation: A U-shaped journey towards sustainable development	env	Panel	China	0.122	6783	10.146	0.122	0.123	0.000	0.012
48	[64]	Green creativity, responsible innovation, and product innovation performance: A study of entrepreneurial firms in an emerging economy	inn	Survey	China	0.348	230	5.604	0.348	0.363	0.004	0.066

Notes: One extracted effect size per record.

Appendix A.2

Table A2. PRISMA counts.

Stage	Item	Count
Identification	Records identified from databases	1423
Identification	Records identified from other sources	0
Screening	Records after duplicates removed	1100
Screening	Records screened (title/abstract)	225
Screening	Records excluded (title/abstract)	875
Eligibility	Full-text articles assessed for eligibility	215
Eligibility	Full-text articles excluded	10
Included	Studies included in the qualitative synthesis	48
Included	Studies included in quantitative synthesis (meta-analysis)	48

Appendix A.3

Table A3. Full-text exclusion reasons.

Full-Text Exclusion Reason	*n*
Not empirical/not firm-level	30
Not GPI/GPrI (wrong exposure)	64
Not performance outcomes (wrong outcome)	38
Insufficient statistics to compute the effect size	21
Duplicate/overlapping sample	14
Other (specify)	0

Appendix A.4

Table A4. Coding scheme for innovation type moderator.

Field	Definition	Allowed Values/Examples	Coding Note/Decision Rule
GI operationalization (verbatim)	How GI was measured in the primary study (copy wording from Measures/Methods)	e.g., "green innovation (overall) scale"; "green product innovation"; "green process innovation"	Copy verbatim from the construct measurement description.
Innovation type (moderator)	Category used in subgroup analysis	GPI/GPrI/Integrated GI	Code based on the construct(s) linked to the extracted effect size (*r*).
Rule for GPI	Product-focused GI construct	"green product innovation", eco-product development, green product design	If the study measures only product-related GI and reports an effect size for that construct, code as GPI.
Rule for GPrI	Process-focused GI construct	"green process innovation", cleaner production, pollution-prevention process improvements	If the study measures only process-related GI and reports an effect size for that construct, code as GPrI.
Rule for Integrated GI	Single unidimensional/composite GI scale covering both product and process aspects	"overall green innovation", "green innovation capability" measured as one composite construct	If GI is operationalized as a single composite/unidimensional scale that simultaneously reflects product and process dimensions (rather than two separate constructs), code as Integrated GI. This is not an artificial aggregation of separate GPI and GPrI effect sizes; it reflects the primary authors' measurement design.
Ambiguous/mixed reporting	Insufficient detail to determine type	Unclear	If the paper does not describe the scale content or mixes multiple industries/constructs without clarity, mark as Unclear and exclude from innovation-type subgroup if needed (document decision).

Note: When a study reports separate effect sizes for GPI and GPrI, each effect size is coded according to its corresponding construct (GPI or GPrI). When only an overall GI effect size is reported based on a single composite scale, it is coded as Integrated GI.

Appendix A.5

Table A5. Coding scheme for industry moderators.

Field	Definition	Allowed Values/Examples	Coding Note
Industry original	Industry descriptor as reported in the paper (verbatim).	e.g., manufacturing; chemical; energy; SMEs; mixed	Copy verbatim from the Methods/Data section.
Industry standardized	Standardized industry label for cross-study comparison.	e.g., Manufacturing; Energy; Chemicals; Construction; Mixed	Map to a consistent label set; keep "Mixed/Multiple" if unclear.
Pollution intensity	Industry pollution intensity group used for moderation.	High-pollution/Low-pollution/Mixed/Unclear	Document the exact rule used; keep "Unclear" if the paper does not specify.

Appendix A.6

Table A6. Coding scheme for geography moderators.

Field	Definition	Allowed Values/Examples	Coding Note
Country primary	Primary country of the sample (single-country).	China; Turkey; Vietnam; Mexico; etc.	If multi-country, leave blank and use "multi_country = 1".
Multi country	Indicator for multi-country sample.	0/1	1 if the paper uses multiple countries/regions.
Geo group moderator	Geographic grouping used for moderator analysis.	China/Multi-country/Other/Unclear	Use the same grouping consistently across all studies.

Appendix A.7

Table A7. Study quality appraisal criteria.

Item	Criterion	Score (0/1)
Q1: Clear construct operationalization	Measures of green innovation and performance are clearly defined and sourced/validated (e.g., established scales, objective indicators).	[__]
Q2: Sample representativeness	Sampling strategy is described and sample is appropriate for inference (e.g., response rate reported for surveys; firm selection explained for panels).	[__]
Q3: Adequate control variables	Models include key confounders (e.g., firm size, age, industry, R&D, ownership) or justify omissions.	[__]
Q4: Endogeneity handling	Addresses endogeneity (e.g., IV/2SLS, GMM, fixed effects, lagging, propensity scores) or discusses limitations.	[__]
Q5: Reliability/validity checks	Reports reliability/validity (e.g., Cronbach's alpha, CFA, HTMT) for survey constructs or robustness checks for objective measures.	[__]
Q6: Transparent reporting of statistics	Reports sufficient statistics to compute/verify effect sizes (r, t/F, beta with SE, N) and clear model specification.	[__]
Q7: Appropriate analysis design	Design aligns with research question (e.g., temporal ordering for causal claims; multi-source data where needed).	[__]
Q8: Sensitivity/robustness analyses	Includes robustness/sensitivity analyses (e.g., alternative measures, subsamples, robustness to outliers).	[__]

Notes: Score each item as 0/1; report total score.

Appendix A.8

Table A8. Methodological Quality Appraisal Scores for Included Studies (k = 48).

ID	Study (Citation)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Total
1	[19]	1	1	1	1	1	1	1	1	8
2	[20]	1	1	1	1	1	1	1	0	7
3	[21]	1	1	1	1	1	1	1	1	8
4	[22]	1	1	1	1	1	1	0	1	7
5	[23]	1	1	1	0	1	1	1	1	7
6	[24]	1	1	1	1	1	1	1	0	7
7	[2]	1	1	1	1	1	1	1	1	8
8	[25]	1	1	1	1	1	1	1	0	7
9	[26]	1	1	0	0	1	1	1	1	6
10	[27]	1	1	1	0	1	1	1	1	7
11	[28]	1	0	1	0	1	1	0	1	5
12	[29]	1	1	1	1	1	1	1	1	8
13	[30]	1	1	1	1	1	1	1	0	7
14	[31]	1	1	1	1	1	1	0	1	7

Table A8. *Cont.*

ID	Study (Citation)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Total
15	[32]	1	1	1	0	1	1	0	0	5
16	[33]	1	1	1	1	1	1	1	0	7
17	[34]	1	1	1	1	1	1	1	1	8
18	[35]	1	1	0	1	1	1	1	1	7
19	[36]	1	1	1	1	1	1	1	1	8
20	[37]	1	1	1	1	1	1	1	1	8
21	[38]	1	0	1	0	1	1	1	1	6
22	[39]	1	1	1	0	1	1	1	0	6
23	[40]	1	1	1	1	1	1	1	1	8
24	[41]	1	1	1	1	1	1	1	1	8
25	[42]	1	1	0	0	1	1	1	1	6
26	[43]	1	1	1	1	1	1	1	1	8
27	[44]	1	1	1	0	1	1	1	0	6
28	[45]	1	1	0	0	1	1	1	1	6
29	[46]	1	0	1	0	1	1	0	1	5
30	[47]	1	1	1	0	1	1	1	0	6
31	[48]	1	1	1	0	1	1	1	1	7
32	[49]	1	1	1	1	1	1	1	0	7
33	[50]	1	0	1	0	1	1	0	0	4
34	[51]	1	1	0	0	1	1	0	1	5
35	[52]	1	1	1	1	1	1	1	1	8
36	[53]	1	1	1	1	1	1	1	0	7
37	[54]	1	1	1	1	1	1	1	1	8
38	[55]	1	1	1	1	1	1	1	0	7
39	[56]	1	1	1	0	1	1	0	1	6
40	[4]	1	1	1	0	1	1	1	1	7
41	[57]	1	0	0	0	1	1	1	0	4
42	[58]	1	1	1	0	1	1	1	0	6
43	[59]	1	0	1	0	1	1	0	1	5
44	[60]	1	1	1	0	1	1	1	0	6
45	[61]	1	1	1	0	1	1	0	0	5
46	[62]	1	1	1	1	1	1	1	1	8
47	[63]	1	1	1	1	1	1	1	0	7
48	[64]	1	1	0	0	1	1	0	1	5

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