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Impact mechanism of green supply chain management on enterprise innovation performance, mediating role of strategic flexibility and moderating effect of environmental scanning

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Abstract: In view of the problem that traditional green supply chain management (GSCM) cannot stably improve enterprise innovation performance (IP) due to the lack of systematic mechanism analysis, this paper proposes a comprehensive analysis method based on the structural equation model (SEM), taking strategic flexibility (SF) as the mediating variable and environmental scanning (ES) as the moderating variable to reveal its causes and solutions. This study first quantifies the level of green practice by designing measurement indicators of GSCM and collecting enterprise data. Then, the scale of SF is developed, and data is collected to test its role as a mediating variable. Next, the ES scale is designed, and its moderating effect is verified through interaction analysis. Finally, the objective data of enterprise IP is taken as the dependent variable, and the SEM is constructed to analyze the effects of each variable. The experimental results show that based on the method of this paper, under high environmental scanning conditions, GSCM can achieve an enterprise innovation performance of 5.5 (maximum 6.0) through strategic flexibility, which provides a theoretical basis and practical guidance for optimizing GSCM.

Keywords: *Environmental scanning, Green supply chain, Innovation performance, Strategic flexibility, Structural equation model.*

1. Introduction

GSCM has gradually become an important part of enterprise competitiveness in the context of global sustainable development. Studies have shown that GSCM has attracted widespread attention for its role in promoting IP while improving enterprise economic benefits by optimizing resource utilization and reducing environmental impact [1-3]. As the core driving force for enterprise development, IP is directly related to the consolidation of market competitive position and the establishment of technological advantages [4-6]. However, GSCM has not always shown stable results in practical applications. After implementing green practices, the improvement of IP in some enterprises has not reached the expected level [7-9]. This inconsistency reflects the current disconnect between theory and practice, and the potential value of GSCM has not been fully explored [10-12]. Enterprises need to find effective paths in a dynamic environment to transform green practices into innovative results. However, existing research on the mechanism analysis of this transformation process is still insufficient, which hinders the ability of theory to guide practice.

The relationship between GSCM and enterprise IP has been widely explored in empirical studies. Novitasari and Agustia [13] used purposive sampling method to analyze data from 488 enterprises in the Indonesian Stock Exchange project with the help of STATA 16 and found that GSCM could improve enterprise performance through green innovation. This finding indicated that the intermediate mechanism played a key role in the relationship between green practices and performance. Similar

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indirect paths were also verified in other studies Bag, et al. [14]; Wang and Yang [15] and Siddiqi, et al. [16]. Mubarak, et al. [17] collected data from multiple manufacturing enterprises using a quantitative research method and a structured questionnaire, and applied structural equation modeling technology to analyze the data. He found that Industry 4.0 technology significantly improved green IP through the mediating role of open innovation and green innovation behavior. This result further emphasized the mediating role of technology and innovation behavior in the impact of GSCM. The interaction between the external environment and internal capabilities has also been paid attention to by other scholars Marco-Lajara, et al. [18]; El Baz and Iddik [19] and Das and Hassan [20]. Daddi, et al. [21] conducted a survey of more than 400 enterprises registered in the European Union and used empirical analysis methods to reveal that GSCM can have a positive impact on market competitiveness through the mediating role and direct path of internalization of environmental management systems. This study highlighted the role of management systems in strengthening the effects of green practices, and also reflected the coexistence of direct and indirect paths [22-24]. The shortcomings of these studies are that the analysis of mediating mechanisms is relatively scattered and lacks a systematic framework that integrates external regulatory factors and internal capabilities.

The role of SF and ES in supply chain management has gradually attracted academic attention. Majid, et al. [25] studied the direct impact of network capabilities on strategic flexibility and strategic performance in Pakistani SMEs (Small and Medium Enterprises) through correlation, regression, and bootstrap analysis, and found that network capabilities and strategic flexibility significantly improved strategic performance, while organizational ambidexterity further enhanced this effect. This study revealed the mediating role of SF between external capabilities and performance. Similar mechanisms have also been explored in other contexts Anning-Dorson [26]; Khan, et al. [27] and Verreynne, et al. [28]. Atkinson, et al. [29] analyzed data collected from 83 agent managers of Iranian insurance enterprises through SEMs and found that competitive intelligence indirectly improved organizational agility through strategic flexibility, indicating that SF is more effective than internal innovation in transmitting external information in a dynamic environment. This finding emphasizes the reliance of SF on external information perception, and the role of similar external factors in GSCM is also worthy of attention Li, et al. [30]; Shekarian and Mellat Parast [31] and Bal and Izak [32]. Ayaz [33] confirmed that GSCM practices enhanced the environmental performance of enterprises by analyzing data from 212 supply chain professionals. This result highlighted the role of external integration in supply chain collaboration in promoting performance, which was potentially related to the adaptive function of SF [34-36]. The shortcoming of these studies is that they do not integrate SF and ES for analysis, and ignore the potential of the two to interact and influence IP in GSCM.

This paper aims to reveal the internal mechanism of GSCM's impact on enterprise IP, explore the root cause of the instability of traditional methods, and propose optimization paths. Through the measurement indicators of GSCM and the collection of enterprise data, the practice level is quantified; the scale of SF is developed, and data is collected to test its mediating role; the ES scale is designed, and its moderating effect is verified through interaction analysis; the objective data of IP is used as the dependent variable to analyze the effect relationship between the variables. This method closely combines the themes of GSCM and IP. SF is used as a mediating variable to explain how green practices affect innovation by improving enterprise adaptability, and ES is used as a moderating variable to reveal the reinforcing effect of external information perception on this process. The research results show that GSCM indirectly drives IP through SF, and ES enhances the intensity of this influence, providing a new perspective for theoretical development and practical application.

2. GSCM Mechanism

2.1. Hypotheses on Variable Relationships

The analysis of GSCM's influence on IP hinges on a framework integrating SF and ES as key elements. GSCM, spanning procurement, production, logistics, and recycling practices, impacts IP by streamlining resources and generating sustainable outcomes that align with market needs. This direct connection stems from the inherent synergy between green initiatives and the emergence of innovative processes or products, positioning IP as a tangible result of GSCM efforts. The relationship reflects an operational dynamic where efficiency gains translate into performance enhancements, underscoring the immediate influence of sustainable practices on organizational advancement.

GSCM also shapes SF, which embodies adaptability in resource distribution, process coordination, and management resilience. Green practices demand responsiveness to evolving environmental standards, prompting enterprises to cultivate flexible strategies that address shifting conditions. SF arises as a pivotal link through which GSCM extends its reach, highlighting the necessity of agility in managing sustainability challenges. This interplay fosters an organizational capacity to reconfigure operations, establishing SF as an intermediary that amplifies the scope of green efforts beyond their initial implementation.

SF subsequently affects IP by converting adaptive strengths into concrete innovative results. The flexibility nurtured by GSCM equips enterprises to pursue novel solutions, leveraging responsiveness to secure competitive advantages. This pathway positions SF as a mediator, directing the operational shifts initiated by GSCM toward outcomes that elevate IP. The mediation process reflects an alignment where adaptability bridges green practices and innovation, ensuring strategic adjustments contribute to performance goals.

ES, involving the systematic tracking of market trends, competitor behaviors, and regulatory changes, alters the intensity of these relationships. The linkage between GSCM and SF strengthens under robust ES, as awareness of external factors refines the adaptability stemming from green practices. Enterprises attuned to their surroundings align flexible strategies more precisely with sustainability objectives, enhancing the transformation of GSCM into SF. Likewise, ES modifies the SF-IP relationship, intensifying the effectiveness of flexibility in fostering innovation. Elevated environmental insight ensures adaptive strategies target pertinent opportunities, reinforcing the translation of SF into performance improvements.

This framework asserts that GSCM influences IP through two routes: a direct effect grounded in resource optimization and an indirect effect mediated by SF, where adaptability drives innovation. ES enhances both the GSCM-SF connection and the SF-IP connection, serving as a contextual factor that magnifies the overall impact. The interplay among these variables underpins the structural equation model employed in this study, informing the design of measurement indicators and the ensuing path analysis. This approach merges internal operational dynamics with external environmental inputs, offering a comprehensive perspective on how GSCM affects IP. The assumed relationships provide the theoretical foundation for the empirical investigation, ensuring the analysis captures the nuanced roles of SF and ES within the GSCM-IP mechanism. The framework directs the examination of how green practices, through flexibility and environmental awareness, yield innovation outcomes, anchoring the study's methodological and analytical processes. To illustrate the theoretical relationships among GSCM, SF, IP, and ES, Figure 1 presents the conceptual framework guiding this study.

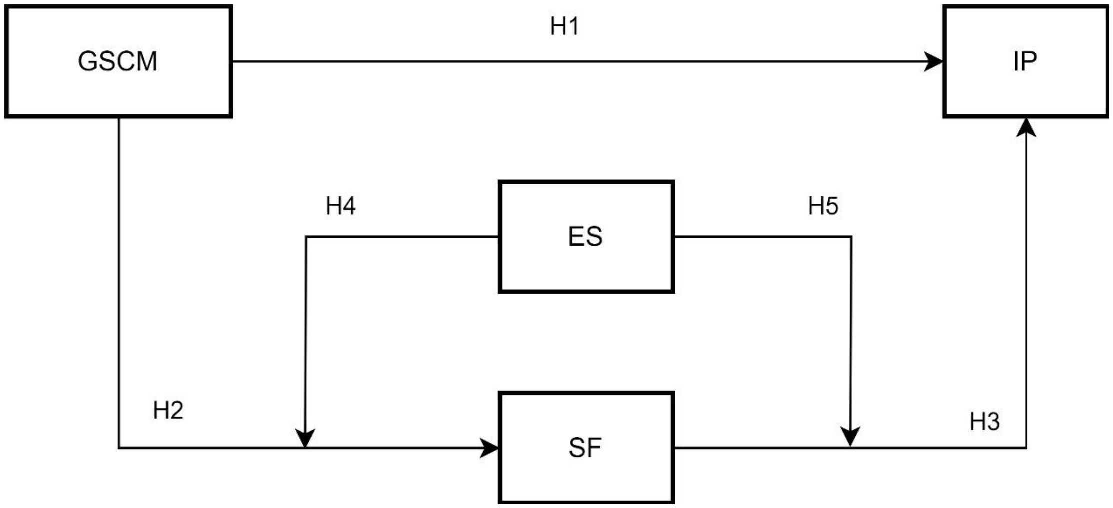

Figure 1.
Conceptual Framework of GSCM Impact on IP with SF and ES.

From the framework diagram in Figure 1, we can see that GSCM affects IP through a direct path (H1) and indirectly affects IP through strategic flexibility (SF), where GSCM promotes SF (H2), and SF further promotes IP (H3). Environmental scanning (ES) serves as a moderating variable, strengthening the relationship between GSCM and SF (H4) and SF and IP (H5).

2.2. Measurement Indicator Design

In the process of designing GSCM measurement indicators, based on the core links of enterprise green practices, a measurement indicator system is constructed around the four dimensions of green procurement, green production, green logistics, and green recycling. In terms of data acquisition, the GSCM information of enterprises is collected through questionnaires and industry reports to ensure the comprehensiveness of the data source. For the green procurement dimension, the focus is on the green practice degree of the enterprise, and the corresponding measurement items are developed. The design of the measurement items adopts the Likert five-level scale, and the values represent the green practice degree of the enterprise in this dimension. After data collection, exploratory factor analysis is utilized to reduce the dimension of the measurement items of this dimension and eliminate low-load items. This process retains measurement items with factor loading values greater than 0.5. The latent variable measurement equation of GSCM is:

$$GSCM = \lambda_1 GP + \lambda_2 GPr + \lambda_3 GL + \lambda_4 GR + \epsilon_1 \quad (1)$$

λ_1 to λ_4 are the factor loadings of green procurement (GP), green production (GPr), green logistics (GL), and green recycling (GR), respectively, and ϵ_1 is the measurement error.

The variance explanation rate equation of factor loading is:

$$R_k^2 = \frac{\sum_{i=1}^{n} p_{ik}^2}{\sum_{i=1}^{n} x_i^2} \quad (2)$$

R_k^2 is the variance explanation rate of the k-th factor; p_{ik} is the loading of the i-th variable on the k-th factor; x_i is the observed value; n is the number of variables.

The measurement indicators of the green production dimension are centered around energy conservation and emission reduction, clean production, and waste treatment in the production process of enterprises. Data is obtained through questionnaire surveys. In the process of constructing the confirmatory factor analysis model, goodness of fit indicators such as χ^2/df, GFI (Goodness of Fit Index), AGFI (Adjusted Goodness of Fit Index), CFI (Comparative Fit Index), TLI (Tucker-Lewis Index), and RMSEA (Root Mean Square Error of Approximation) are selected to test the model fit to ensure that the measurement indicators can effectively reflect the level of green production practices of enterprises. The chi-square test equation of confirmatory factor analysis is:

$$\chi^2 = n \cdot \mathrm{tr}((S - \Sigma)\Sigma^{-1}) \quad (3)$$

χ^2 is the chi-square statistic; n is the sample size; S is the sample covariance matrix; Σ is the covariance matrix of the model estimate; tr represents the matrix trace.

The measurement indicators of the green logistics dimension mainly involve energy conservation and consumption reduction in the transportation process, green packaging, and the construction of a logistics recycling system. Data collection uses the same questionnaire scale design as mentioned above to ensure the consistency of the measurement scale. In the data processing stage, the Cronbach's α coefficient of the sample is calculated. The equation for Cronbach's α coefficient is:

$$\alpha = \frac{N \cdot \bar{c}}{\bar{v} + (N-1) \cdot \bar{c}} \quad (4)$$

N is the number of items; $\bar{c}$ is the average covariance between items; $\bar{v}$ is the average variance of the items, which is used to measure internal consistency.

The equation for average extracted variance is:

$$AVE = \frac{\sum_{i=1}^{k} \lambda_i^2}{k} \quad (5)$$

λ_i is the standardized factor loading of the i-th item; k is the number of items.

The measurement indicators of the green recycling dimension focus on the practices of enterprises in product recycling, reuse of waste materials, and development of circular economy. Data collection still adopts the form of questionnaire scale, and the measurement items are revised after expert group discussion and pre-survey to ensure content validity. Kaiser-Meyer-Olkin (KMO) is utilized to judge the degree to which the data is suitable for factor analysis. In the factor extraction stage, the maximum variance rotation method is used to ensure the interpretability and stability of the extracted factor structure. After the construction of the measurement indicators of the four dimensions is completed, all measurement items are uniformly tested for data quality, and the AVE (Average Variance Extracted) and CR (Composite Reliability) indicators are used for evaluation. The calculation equation of the KMO statistic is:

$$KMO = \frac{\sum_{i \neq j} r_{ij}^2}{\sum_{i \neq j} r_{ij}^2 + \sum_{i \neq j} p_{ij}^2} \quad (6)$$

Among them, r_{ij} is the correlation coefficient between variables i and j, and p_{ij} is the partial correlation coefficient.

The equation for the combined reliability is:

$$CR = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum \theta_i} \quad (7)$$

λ_i represents the standardized factor loading of the i-th measurement item, and θ_i represents the error variance of the i-th measurement item. CR measures the consistency of the latent variable measurement items. Figure 2 shows the distribution of factor loadings of each dimension. Among them, green procurement items include GP1 (prioritization of environmentally friendly raw materials), GP2 (supplier environmental assessment), GP3 (green procurement policy), and GP4 (reduction of disposable materials); green production includes GPr1 (energy-saving equipment), GPr2 (clean production), and GPr3 (emission reduction); green logistics includes GL1 (optimization of paths to reduce carbon emissions), GL2 (green packaging), GL3 (logistics recycling), and GL4 (low-emission vehicles); green recycling includes GR1 (product recycling), GR2 (waste reuse), and GR3 (circular economy).

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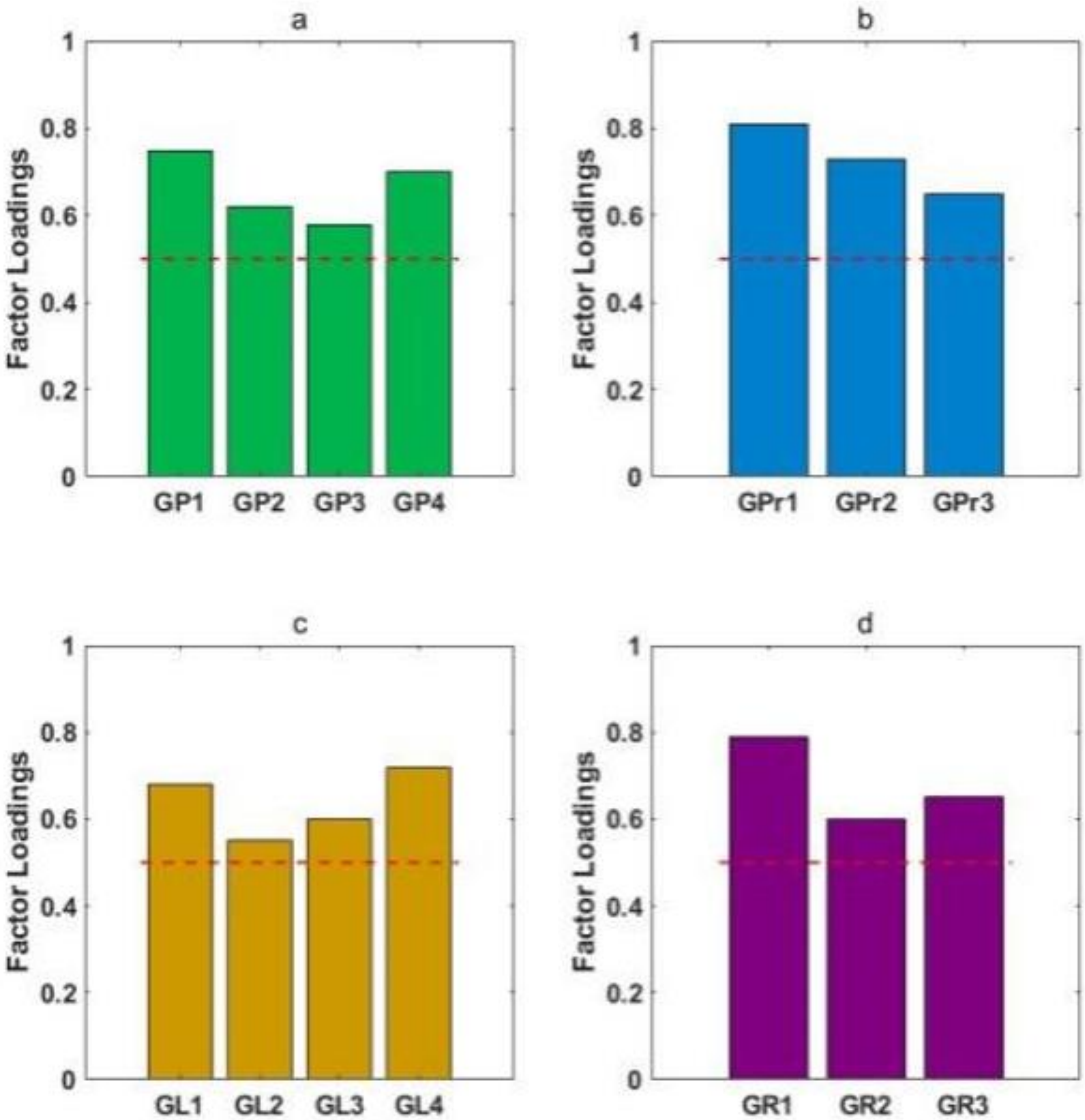

(a) Green procurement
(b) Green production
(c) Green logistics
(d) Green recycling
Figure 2.
Distribution of factor loadings in each dimension.

Figure 2 shows the distribution of factor loadings in the four dimensions of GSCM, with the red dashed line being the 0.5 threshold. Through principal component analysis, all item loadings exceed the 0.5 threshold, verifying the structural validity of the quantitative scoring of green practices.

2.3. Development and Validation of the SF Scale

The development of the SF scale is based on the three characteristics of resource flexibility, coordination flexibility, and management flexibility. The measurement items are designed around the operational behaviors of enterprises in resource allocation, internal coordination, and management

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resilience, and the scientific nature and structural stability of the scale are verified through multiple rounds of empirical data analysis. In the process of item development, the Delphi method is used to collect opinions in multiple rounds, and the core behavioral indicators are extracted in combination with the operational characteristics of the enterprise to eliminate the ambiguity and inapplicability of the item content. The expert group members consist of scholars and senior enterprise managers, and finally select representative and operational measurement items through consistency testing.

After the scale items are initially determined, a survey is conducted to collect data, and the item discrimination is screened using the item analysis method. The critical ratio of the items is calculated, and the items with the critical ratio lower than the critical standard are excluded, ensuring that the measurement tool is significant in distinguishing high and low levels of strategic flexibility. In the process of data cleaning, missing values and outliers are checked, and the expectation maximization algorithm is used to complete the data. After the data cleaning is completed, the scale structure verification stage is entered.

The scale structure verification is based on the factor analysis and measurement model fitting process. The principal axis factor method is used for factor extraction, and the characteristic root and factor contribution rate are calculated. The items with factor loading less than 0.5 or cross-loading are eliminated to ensure that each measurement dimension has singleness and explanatory power. The factor rotation adopts the Promax oblique rotation method, allowing a certain correlation between the latent variables to meet the inherent linkage characteristics of SF in the actual situation. The goodness of fit indexes of the model such as χ^2/df, GFI, AGFI, CFI, TLI, and RMSEA are calculated. If the χ^2/df value is less than 3; the CFI and TLI values are greater than 0.9; the RMSEA value is less than 0.08, the model is considered to be well fitted. During the fitting process, the model is corrected by the correction index for the local error covariance relationship of the model to eliminate the unreasonable correlation between errors. After the correction, the model fit goodness index fully reaches the acceptable standard, indicating that the scale structure has strong explanatory power and applicability. The equation for the mediating effect path of SF is:

$$SF = \beta_1 GSCM + \zeta_1 \quad (8)$$

SF is strategic flexibility; β_1 is the path coefficient of GSCM to SF; ζ_1 is the error term.

The equation for the mediating effect of SF on IP is:

$$IP_{\mathrm{med}} = \beta_2 SF + \zeta_2 \quad (9)$$

IP_{med} is IP under the mediating effect model; β_2 is the path coefficient of SF to IP_{med}; ζ_2 is the error term.

The GFI calculation equation is:

$$\mathrm{GFI} = 1 - \frac{\mathrm{tr}[(S-\Sigma)^2]}{\mathrm{tr}(S^2)} \quad (10)$$

S is the sample covariance matrix; Σ is the covariance matrix of the model estimate; tr represents the matrix trace.

The AGFI calculation equation is:

$$\mathrm{AGFI} = 1 - (1 - \mathrm{GFI}) \cdot \frac{p(p+1)}{2df} \quad (11)$$

p is the number of observed variables, and df is the degree of freedom.

The TLI calculation equation is:

$$\mathrm{TLI} = \frac{(\chi_n^2/df_n) - (\chi_m^2/df_m)}{(\chi_n^2/df_n) - 1} \quad (12)$$

The RMSEA calculation equation is:

$$\mathrm{RMSEA} = \sqrt{\frac{\chi^2/df - 1}{n-1}} \quad (13)$$

χ^2 is the model chi-square statistic; n is the sample size; RMSEA measures the degree of deviation between the model and the data.

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To verify the adaptability of the SEM to the research data, Table 1 lists the model fitting results to test whether the relationship between GSCM, SF, IP, and ES is effectively fitted.

Table 1.
Model goodness of fit index.

Fit Index	Observed Value	Recommended Criterion	Acceptable
χ^2/df	2.15	<3	Yes
CFI	0.94	>0.9	Yes
TLI	0.92	>0.9	Yes
RMSEA	0.06	<0.08	Yes
GFI	0.93	>0.9	Yes
AGFI	0.91	>0.9	Yes

The results show that χ^2/df is 2.15; GFI is 0.93; AGFI is 0.91; CFI is 0.94; TLI is 0.92; RMSEA is 0.06. All indexes meet the recommended standards, indicating that the model has a good fit for the data. This confirms that the path relationship of GSCM affecting IP through SF and the moderating effect of ES is effectively supported at the data level, laying a solid foundation for subsequent hypothesis testing.

For the measurement reliability of the scale, CR is calculated, and AVE is used to verify the convergent validity. If the CR value is greater than 0.7 and the AVE value is greater than 0.5, it means that the scale has good consistency and convergent validity in measuring the same latent variable. Figure 3 shows the extreme effects of high ES and low ES on the convergent validity and reliability of the GSCM scales in each dimension, avoiding the intermediate value of the medium ES from blurring the key differences.

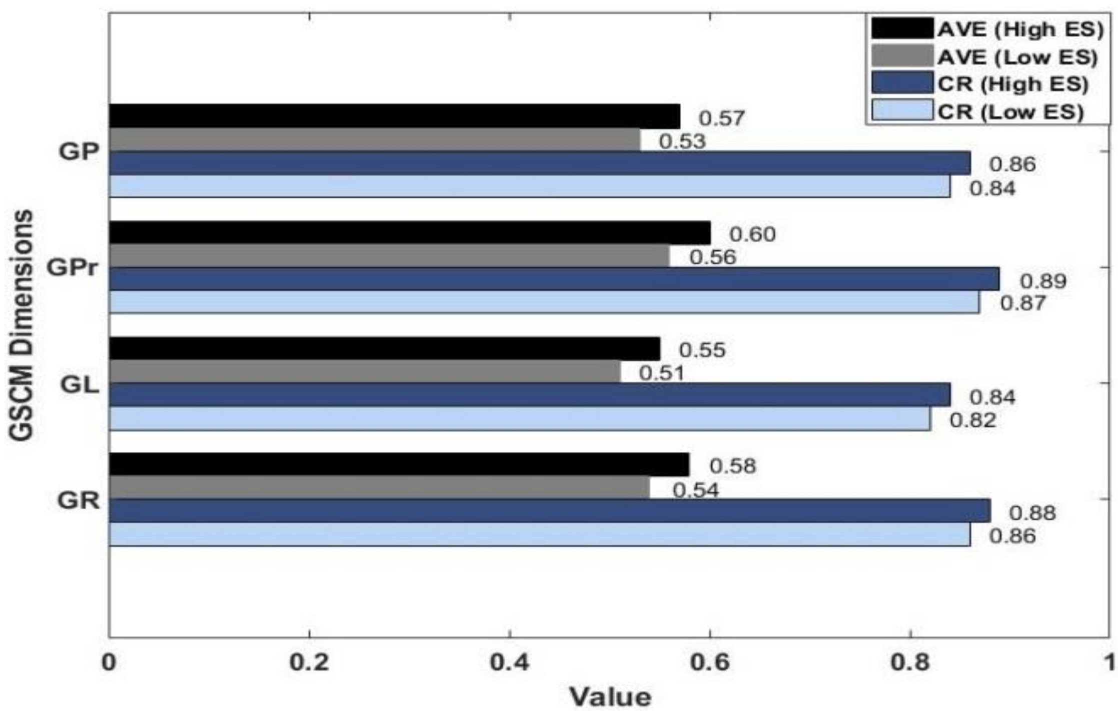

Figure 3.
Convergent validity and reliability of GSCM scales in each dimension.

The results in Figure 3 show that the AVE and CR of all dimensions reach a high level in both the high and low ES groups, indicating that the GSCM scale has excellent consistency and reliability in measuring each dimension. The AVE and CR values of the high ES group are generally higher than those of the low ES group, indicating that when the intensity of environmental scanning increases, the convergent validity of the scale is improved, which is consistent with the fact that when the enterprise's attention to the external environment increases, the measurement structure of GSCM becomes more stable. The AVE and CR differences between the high ES group and the low ES group are small, indicating that the performance of the scale under different environmental scanning intensities is cross-sample stable and does not deviate significantly due to group differences. Figure 4 shows the complete analysis process for verifying the mediating effect of SF between GSCM and IP.

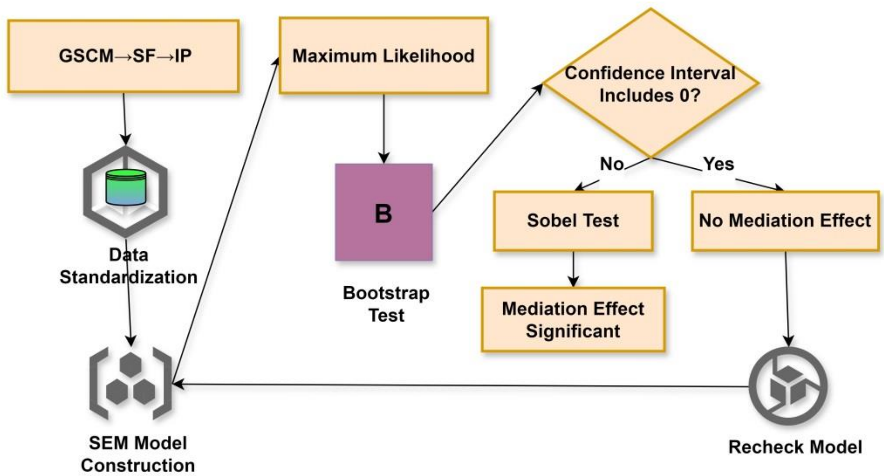

Figure 4.
Analysis process of the mediating effect of SF between GSCM and IP.

As shown in Figure 4, the process starts with setting the theoretical model of GSCM→SF→IP, ensuring variable consistency through data standardization, and then constructing the SEM and estimating the path coefficient using the maximum likelihood method. To test the significance of the mediating effect, the Bootstrap method is used for sampling to determine whether the confidence interval of the indirect effect contained zero; if it does not contain zero, the statistical reliability of the mediating effect is further confirmed by the Sobel test. If the confidence interval contains zero, it indicates that the mediating effect is not significant, and it is necessary to return to recheck the model setting or data processing. This flowchart clearly presents the systematic steps of the mediating effect test, ensures the robustness and scientificity of the analysis results, and provides methodological support for studying the intermediate mechanism of GSCM affecting IP.

2.4. ES Scale Design and Interaction Items

The ES scale design is based on three key dimensions: market dynamics, competitor behavior, and policies and regulations, and comprehensively captures the impact of the external environment on GSCM. In the design of the scale items, the environmental analysis framework of multiple fields is borrowed, and environmental variables closely related to the enterprise IP are extracted through literature review and expert consultation. Each item in the questionnaire measures the perception and response ability of the enterprise to environmental changes. The content of the items is reviewed and revised by the expert group to ensure its applicability and scientificity.

In the process of validating the scale, the two indicators of convergent validity and discriminant validity are used for testing. Convergent validity is verified by calculating the AVE and composite reliability of each dimension to confirm that each dimension has high consistency and reliability. The discriminant validity test uses the Fornell-Larcker criterion to ensure that the correlation between latent variables does not exceed their AVE values to avoid excessive overlap between latent variables. In addition, multi-group analysis is used to further verify the cross-sample stability of the ES scale.

The interaction term analysis uses regression analysis to construct the interaction term and test its impact on GSCM and IP. Through regression analysis of the interaction term between ES and GSCM, the creation of the interaction term is based on the multiplication of the standardized value of ES and the standardized value of GSCM score to ensure that the interaction term can reflect the joint effect of the two. The regression model is fitted by the stepwise regression method, and the interaction term is gradually applied to test its contribution to the overall fit of the model. Finally, the moderating effect of the interaction term and its strength are confirmed by calculating the standardized regression coefficient and significance level. In addition, the Bootstrap method is used to calculate the confidence interval of the interaction term through multiple resampling to verify the significance of the moderating effect; if the interval does not contain zero, it indicates that ES has a significant moderating effect. At the same time, multicollinearity must be avoided to ensure that the correlation between variables is reasonable.

The moderating effect equation of ES is:

$$IP_{\text{mod}} = \beta_4 SF + \beta_5 (SF \times ES) + \epsilon_3 \quad (14)$$

IP_{mod} is IP under the moderating effect model; β_4 is the path coefficient of SF to IP_{mod}; β_5 is the moderating effect coefficient of the interaction term SF×ES; ϵ_3 is the error term.

The standardized regression coefficient equation of the interaction term is:

$$\beta_5 = \frac{\text{Cov}(SF \times ES, IP_{\text{mod}})}{\sqrt{\text{Var}(SF \times ES) \cdot \text{Var}(IP_{\text{mod}})}} \quad (15)$$

Among them, Cov is the covariance, and Var is the variance.

2.5. SEM Construction and Path Analysis

During the model construction process, each dimension of GSCM is classified as a latent variable. SF is measured through three dimensions: resource flexibility, coordination flexibility, and management flexibility. ES is evaluated through dimensions such as market dynamics, competitor behavior, and policies and regulations. When estimating the model, the parameter settings are continuously optimized based on the model's fit index to ensure that the relationship between variables can accurately reflect the actual situation. Specifically, by calculating the direct impact of GSCM on SF and IP, and the indirect impact of SF on IP, the path of how GSCM indirectly affects IP through SF is revealed. The direct effect equation of GSCM on IP is:

$$IP_{\text{direct}} = \gamma_1 GSCM + \epsilon_2 \quad (16)$$

IP_{direct} is IP under the direct effect model; γ_1 is the direct effect coefficient of GSCM on IP_{direct}; ϵ_2 is the error term.

The path effect of the complete mediating model is:

$$IP_{\text{full}} = \gamma_1 GSCM + \beta_3 SF + \zeta_3 \quad (17)$$

IP_{full} is IP under the complete mediating model; γ_1 is the direct effect coefficient of GSCM; β_3 is the mediating effect coefficient of SF; ζ_3 is the error term.

The comparative fit index equation of the structural equation is:

$$CFI = 1 - \frac{max(\chi^2 - df, 0)}{max(\chi^2_{\text{null}} - df_{\text{null}}, 0)} \quad (18)$$

CFI is the comparative fit index; χ^2 and df are the chi-square value and degree of freedom of the model; χ^2_{null} and df_{null} are the values of the model.

The interaction term between GSCM and SF is constructed and applied into the model to examine its impact on IP. The moderating effect is tested by adding the interaction term of ES in the path analysis and testing its impact on the relationship between GSCM and SF at different ES levels. Figure 5 shows the interaction relationship between ES level (-3, 3), GSCM score (-4, 4), and IP (-4, 6).

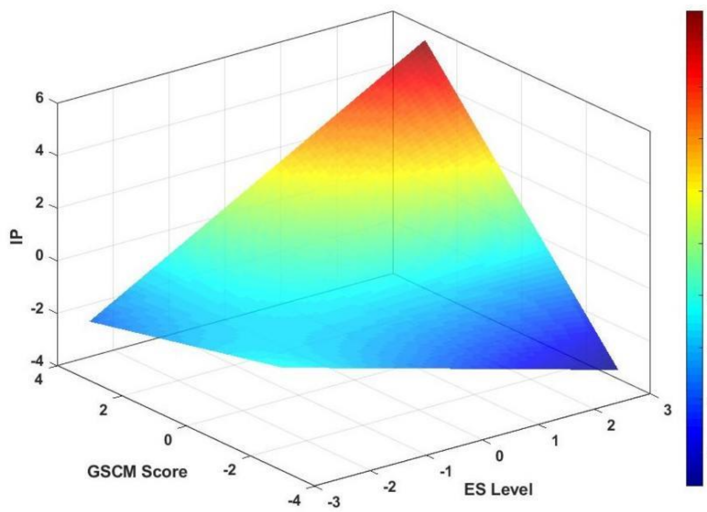

Figure 5.
Interaction between ES, GSCM, and IP.

The results in Figure 5 show that when the ES level is high, the positive impact of GSCM on IP is significantly enhanced. The surface shows a significant bulge in the area of high ES level and high GSCM score, which verifies that the moderating effect of ES provides key external support for the transformation of green practices into innovative results and provides an intuitive basis for optimizing GSCM strategies.

In the process of testing the SEM, to avoid overfitting of the model, stepwise regression and multicollinearity test are used. By calculating the variance inflation factor, it is ensured that there is no excessive correlation between the independent variables to prevent the collinearity problem from affecting the estimation results. The model estimation results show that GSCM has a significant impact on SF, and the impact path of SF on IP is also confirmed. ES plays a significant moderating role in this process. After testing and analyzing the path coefficients between various variables, the mechanism of GSCM indirectly affecting the IP of enterprises by improving SF is finally confirmed, and the important role of ES as a moderating variable in this process is revealed. The analysis results of the SEM provide theoretical support for optimizing the GSCM strategy and lay a data foundation for subsequent research in related fields. The equation for calculating the variance inflation factor of multicollinearity is:

$$VIF = \frac{1}{1-R_{SF,ES}^2} \quad (19)$$

VIF is the variance inflation factor of SF and ES, and $R_{SF,ES}^2$ is the square of the multiple correlation coefficient between SF and ES.

Figure 6 shows the empirical research process of the GSCM affecting the IP mechanism of enterprises.

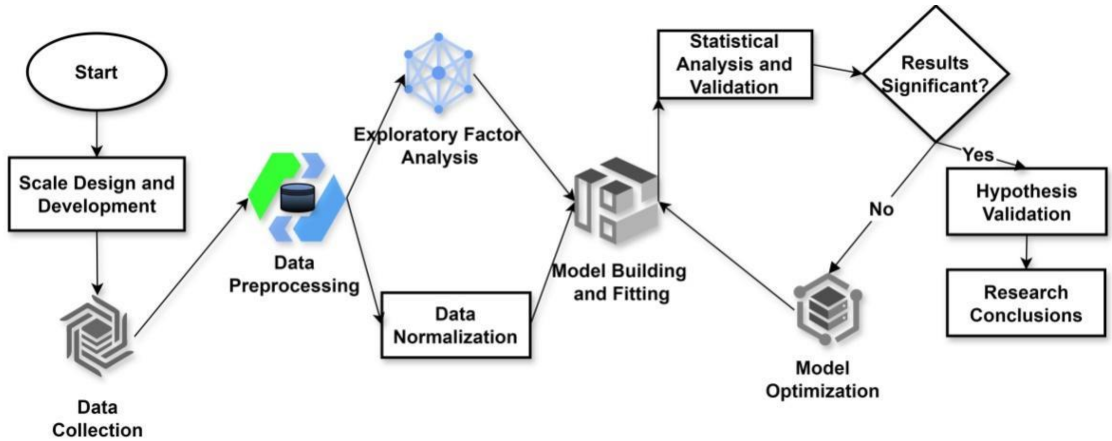

Figure 6.
Empirical research process of the GSCM affecting the IP mechanism of enterprises.

As shown in Figure 6, the process begins with the design and development of measurement scales to quantify key structures, and then collects data through surveys and industry reports. Subsequent data cleaning and preparation include preliminary factor analysis to improve structural validity and data normalization to ensure consistency of analysis. These steps ultimately lead to the construction and fitting of statistical models, which are then rigorously analyzed to verify the impact of the hypotheses. If the results show statistical significance, the hypothesis is confirmed; otherwise, the model is optimized and re-evaluated. This iterative process ultimately produces actionable research results and provides a structured approach.

3. Verification of the GSCM Mechanism Effect

The quantitative scoring of green practices adopts the Likert five-level scale, setting measurement items such as green procurement, green production, green logistics, and green recycling, and requires enterprises to score according to their actual situation. By collecting data and calculating Cronbach's α coefficient for reliability test, the KMO test and Bartlett sphericity test are performed on the data to verify the sample fit. If the KMO value reaches 0.7 or above and the Bartlett test is significant ($p<0.001$), it indicates that the data is suitable for factor analysis. Finally, the average score of each item is used as the quantitative score of green practice, and the dimensional difference is eliminated through standardized transformation to ensure that the path analysis of each dimension data is at the same level. Table 2 is the results of the mediating effect test.

Table 2.
Results of the mediating effect test.

Dimension	Cronbach's α	KMO	Percent Variance Explained
Green Procurement(GP)	0.85	0.78	62%
Green Production (GPr)	0.88	0.82	65%
Green Logistics (GL)	0.83	0.75	60%
Green Recycling (GR)	0.87	0.80	63%
Total	0.90	0.81	62.5% (avg)

According to the data in Table 2, the Cronbach's α values are all high, indicating that the measurement consistency of each dimension is high and the results are reliable. The KMO values of each dimension are all over 0.7, and the average variance explanation percentage is 62.5%, indicating that the scale can effectively capture the core information of green practice.

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The mediating effect test adopts the SEM method, and the proportion of the indirect effect in the total effect is calculated to quantify the conduction strength of the mediating variable. The Sobel test is used to calculate the standard error and Z value to assist in verifying the consistency of the results of the Bootstrap method. The model fit goodness test ensures the rationality of the model structure and path relationship. The indirect effect calculation equation of the mediating effect is:

$$IE = \beta_1 \cdot \beta_3 (20)$$

IE is the indirect effect of GSCM on IP through SF; β_1 is the path coefficient of GSCM on SF; β_3 is the mediating effect coefficient of SF.

The statistical equation of the Sobel test is:

$$Z = \frac{\beta_1 \cdot \beta_3}{\sqrt{\beta_3^2 SE_1^2 + \beta_1^2 SE_3^2}} (21)$$

Z is the Sobel test statistic; β_1 and β_3 are the path coefficients; SE_1 and SE_3 are their standard errors.

The moderating effect test adopts the interactive regression analysis method. The GSCM and ES variables are first standardized to generate the interactive term variable, and the interactive term is applied into the SEM. To further verify the stability of the moderating effect, the multi-group analysis method is used to divide the sample into three groups according to the ES strength, and the path coefficient of GSCM to SF is calculated respectively. The significant difference of the path coefficient is verified by the degree of freedom difference test. The Johnson-Neyman method is used to calculate the significant interval of the interaction effect and analyze the dynamic impact of the change of ES strength on the path effect. The Johnson-Neyman critical interval equation of the moderating effect is:

$$ES_{\text{crit}} = -\frac{\beta_4}{\beta_5} \pm \frac{t_{\alpha/2} \cdot SE_{\beta_5}}{\beta_5} (22)$$

ES_{crit} is the critical value of ES; β_4 is the path coefficient of SF to IP_{mod}; β_5 is the interaction term coefficient; $t_{\alpha/2}$ is the t value at the significance level; SE_{β_5} is the standard error.

Table 3 shows the path coefficient of GSCM to SF after being divided into three groups of high, medium, and low according to ES strength.

Table 3.
Comparison of path coefficients of GSCM to SF under multi-group analysis.

Group	Sample Size	β	SE_{β_5}	p	$\Delta\chi^2$	ES Threshold Range	IP
High ES(1,3)	100	0.60	0.06	0.0001	10.5 (High vs Medium)	> 0.8	5.5
Medium ES(-1,1)	90	0.40	0.07	0.0005	8.2 (Medium vs Low)	-0.5 to 0.8	4.5
Low ES (-3,-1)	85	0.18	0.08	0.0009	12.8 (High vs Low)	< -0.5	3.0

The results in Table 3 show that under high ES conditions, the path coefficient of GSCM to SF is 0.60, and the enterprise IP is 5.5; under low ES, the path coefficient drops to 0.18, and the enterprise IP is reduced to 3.0. This reveals the key role of ES in enhancing the transformation of green practices into innovative results.

4. Conclusions

This paper systematically analyzes the impact mechanism of GSCM on enterprise IP by constructing SEMs, and verifies the role of SF as a mediating variable and ES as a moderating variable. The study first designs and quantifies the measurement indicators of GSCM, combines the SF and ES scales, collects enterprise data, and uses maximum likelihood estimation and Bootstrap methods to reveal the path of GSCM indirectly improving IP through SF. The results show that under high ES conditions, GSCM makes IP reach 5.5 (maximum 6.0) through SF, which provides clear theoretical support and practical guidance for optimizing GSCM. However, this paper does not analyze the dynamic evolution of the interaction effect of SF and ES, and does not fully consider the impact of enterprise size differences on model adaptability. Future research should apply dynamic analysis methods to explore the changes in the effects of GSCM at different time stages, and at the same time incorporate enterprise scale variables to verify the applicability of the model among enterprises of different sizes, so as to improve the theoretical framework and enhance the practical application value.

Transparency:
The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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