

The Impact of ESG Performance on enterprises' Innovation Efficiency - Evidence from Chinese Listed Companies

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Abstract. Improving enterprise innovation efficiency and realizing enterprise innovation development is the basis for promoting high-quality development in China. Studying the impact of ESG performance on enterprise innovation efficiency not only helps enterprises find new growth points and innovation drivers in the context of sustainable development, but also helps to enhance their long-term competitiveness and market position. This paper thus seeks to examine the relationship between ESG performance and enterprise innovation efficiency, with a view to elucidating the manner in which ESG performance affects enterprise sustainable development. To this end, the paper employs a combination of theoretical analysis and empirical investigation, using data from Chinese A-share listed companies. It is found that good ESG performance improves enterprise innovation efficiency, and the robustness test further supports the conclusion. The mechanism analysis based on the dual dimensions of information transparency and financing constraints indicates that ESG performance improves enterprise innovation efficiency mainly through improving information transparency and alleviating financing constraints. Heterogeneity analysis shows that ESG performance has a more significant role in improving enterprise innovation efficiency in the eastern region, non-heavily polluted industries, and larger enterprises. This paper employs an innovative approach, beginning with an examination of the ESG perspective and a comprehensive examination of the multidimensional results of ESG responsibility fulfillment. In particular, it combines ESG with enterprise innovation efficiency, thereby filling a current research gap and providing empirical insights for a range of stakeholders, including enterprises, governments, and financial institutions.

Keywords: ESG Performance, Innovation Efficiency, Information Transparency, Financing Constraints.

1. Introduction

In recent years, global discussions on environmental, social and enterprise governance have intensified, and ESG performance has gradually become an important indicator of enterprise sustainability and the realization of social value. The United Nations Development Summit has repeatedly emphasized ESG as an important component of sustainable development. In addition, ESG-related topics have been widely discussed in the community, and the annual ESG China Forum Innovation Conference has focused on deepening the concept of ESG and establishing an ESG ecosystem, etc. ESG performance is playing an increasingly important role in China's economic development.

Currently, a large number of scholars have explored and researched the impact of ESG performance on business behavior. On the financial side, superior ESG performance can improve enterprise profitability in two ways: by building a good brand image and enhancing brand value and by harvesting stakeholders' trust and strengthening risk resistance[1]. In terms of innovation, good ESG performance can promote enterprises' innovation output, enhance enterprises' R&D intensity, and increase technician intensity[2]. In terms of risk, Zhao Li et al. found that ESG rating divergence is also large, the higher the business risk of the enterprise[3]. For enterprise innovation efficiency, ESG performance improves enterprise innovation efficiency by alleviating enterprise debt financing constraints, improving enterprise transparency, and increasing analyst attention [4]. It has also been shown that ESG performance can promote the investment of enterprise innovation resources and

reduce the constraints on resources, which in turn improves enterprise innovation efficiency[5]. In addition, existing studies pay more attention to the impact of ESG performance on enterprises' innovation efficiency, and it is generally recognized that good ESG performance can promote enterprises' innovation efficiency[6].

This paper examines the influence of ESG performance on enterprise innovation efficiency from both theoretical and practical viewpoints. It demonstrates that exemplary ESG performance can facilitate the enhancement of enterprise innovation efficiency, identifies the mediating variables that shape the impact of ESG performance on enterprise innovation efficiency, and conducts an analysis of regional, industry, and enterprise size heterogeneity. This fills gaps in the relevant theoretical landscape, provides empirical support for the academic community, and broadens the research horizons of innovation efficiency. Practically, this paper guides enterprises to balance ESG and innovation capability, provides new perspectives for investors to assess the long-term value of enterprises, guides capital to focus on sustainable development, and also provides a basis for the government to formulate policies to promote the synergistic development of ESG and innovation.

The marginal contribution of this paper compared to existing studies is: (1) the research perspective of this paper is innovative, most of the research on ESG nowadays focuses on the relationship between ESG on the economic performance of enterprises, the cost of capital, etc., and lacks a comprehensive understanding of the results generated by the fulfillment of the ESG responsibility, and there are few researches that combine ESG and innovation efficiency, and lack of exploration of the influence mechanism of the two and the internal and external conditions of their functioning; (2) in terms of research content, this study constructs a theoretical analysis framework of the influence of ESG performance and innovation efficiency, explores its role mechanism, and empirically tests its influence effect and path mechanism, based on the endowment of the enterprises. Nevertheless, research examining the efficiency of enterprise innovation from an ESG-wide perspective has yet to garner significant attention from scholars.

2. Research hypotheses

2.1. ESG performance and enterprises' innovation efficiency

The aim of enterprises in business is usually to pursue excess economic profits. Due to the problems of long innovation cycle, high cost and many uncertainties, enterprises often prefer to invest in projects with short cycle, low cost and low risk. This behavior is not conducive to the promotion of enterprise innovation efficiency. After the concept of ESG generalization was put forward, the government put forward a series of policies that are conducive to the development of enterprise innovation, such as tax exemptions and fee reductions, and increased credit support. It was found that government subsidies and tax incentives are conducive to strengthening the positive effect of ESG performance on enterprise innovation[7].

This paper focuses on the measurement of enterprise innovation efficiency, which is determined by two key factors: enterprise innovation input and enterprise innovation output. An efficient enterprise will achieve a higher innovation output with a lower innovation input, indicating a higher level of innovation efficiency. From the perspective of enterprises' innovation input, ESG performance can promote enterprises to increase innovation input, which in turn inhibits downside risk[8]. From the standpoint of enterprise innovation output, Fang and colleagues have demonstrated that enterprise ESG performance not only leads to an increase in the quantity of innovation output, but also enhances the quality of innovation[6]. In addition, scholars such as Lv found that enterprise ESG performance can significantly boost enterprise innovation by improving enterprise organizational resilience[9]. Therefore, this paper proposes hypothesis 1:

H1: Good ESG performance can effectively improve enterprises' innovation efficiency.

2.2. ESG Performance, Information Transparency and enterprise Innovation Efficiency

Information transparency is not only the basis for building trust and promoting fair competition, but also the key to improving the quality of decision-making and enhancing the effectiveness of regulation. ESG performance can promote media attention, which in turn promotes the improvement of enterprise information transparency[10]. From the perspective of enterprise agency, based on the theories of information transfer, principal-agent, and information asymmetry, it is found that the information transparency of surplus can promote enterprise technological innovation by alleviating enterprise agency problems[11]. From the perspective of enterprise decision-making behavior, information transparency can alleviate the sensitivity of short-term performance to mandatory changes in management, increase enterprise tolerance for innovation failure, and then encourage enterprise managers to strengthen their investment in innovation[12]. Therefore, this paper proposes Hypothesis 2:

H2: Good ESG performance can improve the efficiency of enterprise innovation by increasing information transparency.

2.3. ESG Performance, Financing Constraints and enterprise Innovation Efficiency

One of the major impediments to enterprise innovation is financing constraints. Meng Mengmeng and colleagues demonstrated that ESG performance can facilitate improvements in financial performance and alleviate financing constraints for enterprises[13]. The financing difficulties of enterprises in China, especially those of small and medium-sized enterprises (SMEs), are very significant, including the low amount of endogenous financing and the difficulty of bank loans[14]. Xiong and other scholars found that the mechanism by which the business environment promotes enterprises' green technological innovation is to alleviate enterprises' financing constraints [15]. Therefore, this paper proposes hypothesis 3:

H3: Good ESG performance can improve enterprises' innovation efficiency by alleviating financing constraints.

3. Study design

3.1. Sample data sources and sample selection

In this paper, companies listed in A-share companies from 2011 to 2021 are selected as the research sample. Because CSI ESG Rating constructs indicators based on domestic and international standards, and after weighted calculation and data cleaning, it can accurately reflect its performance in the ESG field, so the relevant data of ESG performance is from CSI ESG Rating, and all other data are from CSMAR database. The data cleaning work performed in this paper includes excluding the data of listed companies with ST and PT marks and missing observations.

3.2. Description of variables

3.2.1. Implicit variable and Independent variable

The implicit variable in this paper is innovation efficiency (InE). This paper uses the number of patent applications per unit of R&D investment as a comprehensive indicator for measuring innovation efficiency, with the following formula:

$$\text{InE} = \frac{\ln(\text{patent1} \times 3 + \text{patent2} \times 2 + \text{patent3} \times 1 + 1)}{\ln(\text{expenditure} + 1)} \quad (1)$$

Where *patent1*, *patent2* and *patent3*, represent the number of invention patents, the number of utility model patents and the number of design patents, respectively, and *expenditure* represent R&D expenditures.

The independent variable in this paper is ESG performance (ESG). The CSI ESG investment performance rating system adopts a nine-grade rating system, AAA, AA, A, BBB, BB, B, CCC, CC, C. In this paper, the nine grades of ratings are assigned to 9, 8, 7, 6, 5, 4, 3, 2, and 1, respectively.

3.2.2. Control variables

In this paper, with reference to existing studies, enterprise age (Age), enterprise size (Size), gearing ratio (Lez), net gearing ratio (Roe), dual position (Dual), director independence (Indep), total asset turnover (Ato) and regional economic development (gdpgrowth) are selected as control variables.

Table 1. Definition of variables

Type	Name	Symbol	Definition
Explained variables	Innovation Efficiency	InE	Using the number of patent applications per unit of R&D investment as a composite indicator for measuring innovation efficiency
Explanatory variables	ESG Performance	ESG	According to the CSI ESG rating from low to high, the value is assigned as 1~9.
Control variables	enterprise age	Age	Years of business establishment
	enterprise size	Size	The total assets of the enterprise take the natural logarithm
	gearing ratio	Lez	Total liabilities/total assets
	net gearing ratio	Roe	(Total Liabilities - Total Assets)/Total Assets
	dual position	Dual	If the chairman and general manager are the same person, then take the value of 1, otherwise 0
	director independence	Indep	Number of independent directors / number of directors
	total asset turnover	Ato	Business Revenue/Total Assets
	regional economic development	gdpgrowth	Gross Regional Product

3.3. Model construction

In order to examine the impact of enterprise ESG performance on enterprise innovation efficiency, the following model is constructed:

$$InE_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \alpha_j \sum Controls_{i,t} + \sum Industry + \sum Year + \varepsilon_{i,t} \quad (2)$$

where $InE_{i,t}$ is the model explanatory variable representing enterprise i's enterprise innovation efficiency in year t; $ESG_{i,t}$ is the model explanatory variable representing enterprise i's ESG performance in year t; $Controls_{i,t}$ represents the control variable; $\sum Industry$ and $\sum Year$ represent the industry fixed effect and year fixed effect, respectively, which are able to eliminate the influence of variability brought by different industries and time trends on enterprises' ESG performance; $\varepsilon_{i,t}$ is the random disturbance term.

3.4. Descriptive statistics

Table 2 reports the descriptive statistics of the variables of interest. Among them, the mean value of innovation efficiency is 0.205, the standard deviation is 0.092, and the sample skewness is about -0.724. It indicates that the innovation efficiency in China approximates to a left-skewed distribution. the mean value of ESG performance is 4.14, the standard deviation is 1.122, and the sample skewness is about -0.429, which indicates that the ESG performance of Chinese enterprises also approximates to a left-skewed distribution.

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ine	26022	0.205	0.092	0	0.648
esg	26141	4.148	1.122	1	8
age	26141	2.884	0.34	1.099	4.804
size	26141	8.322	1.303	4.009	14.821
lez	25901	0.388	0.205	-0.087	2.127
roe	25497	0.059	0.517	-71.367	8.715
dual	26141	0.308	0.462	0	1
indep	26141	0.377	0.056	0.143	1
ato	26141	0.15	0.126	0	3.554
gdpgrowth	26141	10.122	0.685	6.407	10.882

4. Empirical results and analysis

4.1. Benchmark regression results

Table 3 reports the results of the benchmark regression of ESG performance on enterprises' innovation efficiency. When no control variables are added and the effect of GDP growth on the results is not considered, the impact coefficient of ESG performance on enterprises' innovation efficiency is 0.003, which is significantly positive at the 1% level (see column (1)), indicating that ESG performance improves enterprises' innovation efficiency. The impact coefficient of ESG performance with the addition of control variables (see column (2)), respectively, is 0.001, which is significantly positive at the 1% level. The last column considers the effect of GDP growth with the addition of control variables, and the impact coefficient of ESG performance remains significantly positive. The aforementioned results suggest that the implementation of effective ESG practices can enhance the efficiency of enterprise innovation processes. The initial testing of the hypothesis is presented herewith.

Table 3. Benchmark regression results

	(1) ine	(2) ine	(3) ine
esg	0.003*** (0.0005)	0.001*** (0.0005)	0.001*** (0.0005)
age		0.017*** (0.006)	0.017*** (0.006)
size		0.027*** (0.001)	0.027*** (0.001)
lez		-0.013*** (0.004)	-0.013*** (0.004)
roe		0.001* (0.001)	0.001* (0.001)
dual		0.002 (0.001)	0.002 (0.001)
indep		-0.0005 (0.012)	-0.0004 (0.012)
ato		-0.007 (0.005)	-0.007 (0.005)
gdpgrowth			-0.004 (0.007)
Year-fe	Yes	Yes	Yes
enterprise-fe	Yes	Yes	Yes
_cons	0.148*** (0.003)	-0.099*** (0.021)	-0.059 (0.072)
Observations	26022	25156	25156
R-squared	0.121	0.153	0.153

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

4.2. Robustness Tests

4.2.1. Changing the measurement of explanatory variables

In this paper, taking into account the differences in the input focus of different types of enterprises on the three kinds of patents, the assignment of the importance of the output of the three kinds of patents is canceled, and the calculation formula is reconstructed as follows:

$$\ln E1 = \frac{\ln(\text{patent1} + \text{patent2} + \text{patent3} + 1)}{\ln(\text{expenditure} + 1)} \quad (3)$$

where *patent1*, *patent2*, *patent3* and *expenditure* represent constant content. The results of the test, as shown in column (2) in Table 4, show that the coefficient of the impact of ESG performance on enterprises' innovation efficiency is 0.002, which is significantly positive at the 1% level, supporting the reliability of the main findings of this paper.

4.2.2. Changing the measurement of core explanatory variables

Considering the long period from input to output of enterprise innovation, calculating innovation efficiency based on current output may lead to biased results. Therefore, this paper does lag one period for the core explanatory variables. The test results, as shown in column (3) in Table 4, show that the impact coefficient of ESG performance is significantly positive at the 1% level. This finding suggests that hypothesis 1 remains valid even when the measurement of the core explanatory variables is modified.

Table 4. Robustness test

	(1) ine	(2) ine 1	(3) ine
esg	0.001*** (0.0005)	0.002*** (0.0004)	
esg lag			0.001*** (0.0005)
Controls	Yes	Yes	Yes
Year-fe	Yes	Yes	Yes
enterprise-fe	Yes	Yes	Yes
_cons	-0.015 (0.158)	-0.104* (0.062)	-0.045 (0.075)
Observations	5191	25156	21222
R-squared	0.1	0.18	0.134

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

5. Mechanisms and Heterogeneity Analysis

The previous analysis provides empirical evidence to support that ESG performance can improve enterprises' innovation efficiency. What exactly causes ESG performance to increase enterprises' innovation efficiency is further explored in this section, which explores the underlying mechanisms and analyzes heterogeneity.

5.1. Mechanism analysis

When evaluating the quality of information disclosure of listed companies, SZSE and SHSE pay attention not only to the compliance of mandatory information disclosure, but also to the adequacy and

timeliness of voluntary information disclosure, which helps to reflect more accurately the level of information transparency of listed companies. Therefore, this paper is based on the disclosure information of Shenzhen Stock Exchange and Shanghai Stock Exchange, and A, B, C and D represent the enterprise disclosure ratings of excellent, good, passing and failing, respectively, and assign values of 3, 2, 1 and 0 to A, B, C and D, respectively. Theoretical analysis suggests that ESG performance improves the efficiency of enterprise innovation by increasing enterprise transparency. The relevant results are shown in column (1) of Table 5, and the coefficient of influence of ESG performance on enterprise transparency is 0.14, which is significant and positive at the 1% level, indicating that ESG performance can improve enterprise transparency. High-quality information disclosure can significantly reduce the degree of information asymmetry, and make the internal operation, financial status and strategic planning of the enterprise more transparent. This can enhance investors' trust in the enterprise, restrain and monitor the selfish behavior and short-sighted decision-making tendency of shareholders and management, and prevent them from jeopardizing the long-term development and overall interests of the enterprise for their personal interests or short-term interests. At the same time, high-quality disclosure can also stimulate the innovation vitality of the enterprise, promote the enterprise to continuously explore new business areas and technological frontiers, and then enhance the enterprise's innovation efficiency and market competitiveness. Consequently, the implementation of effective ESG strategies can enhance a enterprise's capacity for innovation by fostering a culture of transparency and accountability. This, in turn, substantiates the veracity of Hypothesis 2.

Another hypothesis obtained from the theoretical analysis is that ESG improves enterprise innovation efficiency by relieving the constraints that arise from enterprise finance. In order to verify this mechanism, this paper calculates the SA index, which measures financing constraints, based on enterprise age and enterprise size, and takes the absolute value for regression analysis. The larger the absolute value of the SA index, the higher the degree of enterprise financing constraints. The regression results are shown in column 5(2) of Table 5. The coefficient of ESG performance on financing constraints is -0.006, which is significant at 1% level, indicating that ESG performance can alleviate enterprise financing constraints. Easing enterprise financing constraints can reduce the obstacles faced by enterprises in seeking financial support, facilitate enterprises' access to the funds needed for innovation, and promote their focus on technological innovation and product upgrading, thereby gaining a greater competitive advantage in the marketplace. In addition, easing enterprise financing constraints can also help to enhance the credit rating and financing capacity of enterprises, laying a solid foundation for their future innovations. Therefore, good ESG performance can improve enterprise innovation efficiency by alleviating enterprise financing constraints and Hypothesis 3 is tested.

Table 5. Mechanism analysis

	(1) opacity	(2) fin
esg	0.14*** (0.006)	-0.006*** (0.0004)
Controls	Yes	Yes
Year-fe	Yes	Yes
enterprise-fe	Yes	Yes
_cons	1.783** (0.896)	3.011*** (0.061)
Observations	25264	25264
R-squared	0.233	0.106

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

5.2. Heterogeneity analysis

5.2.1. Regional heterogeneity

Considering that the eastern region of China encompasses the reform and opening-up development regions, including the Shenzhen Special Zone, Pudong New Area, Yangtze River Delta, Pearl River Delta, and others, and that the eastern region is at the vanguard of development, transformation, reform, and transition, differences in economic status emerge between the eastern region and other regions. Therefore, this paper analyzes the heterogeneity according to the division of the four major economic regions in China, and the results are shown in Table 6. Among them, the coefficient of the impact of ESG performance on the innovation efficiency of enterprises in the eastern region is significantly positive at the 10% level, indicating that ESG performance can improve the innovation efficiency of enterprises in this region. It is positive but not significant in the central and northeastern regions and negative in the western region. For the central region, the possible reasons are the relative scarcity of resources and the serious problem of brain drain. The industrial structure of the central region is dominated by traditional industries and lacks the demand for technological innovation. The northeast region has a single industrial structure, backward ideology, serious brain drain and insufficient policy support, which collectively impede the advancement of enterprise innovation. China's western region is geographically remote, with a weak economic base and low talent density, resulting in enterprises in the western region will face more difficulties in technological innovation.

Table 6. Analysis of regional heterogeneity

	(1) Eastern Region	(2) Middle Region	(3) Western Region	(4) Northeastern Region
esg	0.002* (0.001)	0.001 (0.001)	-0.0003 (0.001)	0.003 (0.003)
Controls	Yes	Yes	Yes	Yes
Year-fe	Yes	Yes	Yes	Yes
enterprise-fe	Yes	Yes	Yes	Yes
_cons	-0.015 (0.158)	-0.047 (0.538)	0.045 (0.073)	1.012 (0.755)
Observations	5191	3433	2960	916
R-squared	0.1	0.19	0.118	0.169

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

5.2.2. Industry Heterogeneity

Differences in the industry's own factor structure and other differences in the degree of demand for technological innovation can lead to significant differences in the utility of ESG performance across industries. Therefore, this paper analyzes the heterogeneity based on heavy pollution industries and non-heavy pollution industries, and the regression results are shown in columns (1) and (2) of Table 7. The results show that the coefficient of influence of ESG performance on enterprises' innovation efficiency in non-heavily polluted industries is significantly positive at the 5% level, while it is not significant for heavily polluted industries. It indicates that ESG performance has a stronger effect on improving the innovation efficiency of enterprises in non-heavily polluted industries compared to heavily polluted industries. In order to analyze the reasons for this, the aforementioned enterprises are divided into two categories: traditional heavy pollution enterprises and knowledge-intensive heavy pollution enterprises. On the one hand, the more traditional heavy polluting enterprises targeting resource extraction and processing, raw material production, and light industry tend to rely on relatively outdated production equipment and low resource utilization efficiency in the production process. However, the cost of breaking through this technical barrier is high, making it difficult for enterprises to afford. On the other hand, for heavy polluting enterprises with high knowledge density,

such as biological and chemical industries, some of the core technologies originate from other countries. This leads to intellectual property rights issues for enterprises, which prevents them from improving their innovation efficiency.

Table 7. Analysis of industry and enterprise heterogeneity

	(1) Non-polluting industries	(2) polluting industries	(1) Large Enterprises	(2) Small and medium-sized enterprises
esg	0.001** (0.001)	0.001 (0.001)	0.001** (0.001)	0.002* (0.001)
Controls	Yes	Yes	Yes	Yes
Year-fe	Yes	Yes	Yes	Yes
enterprise-fe	Yes	Yes	Yes	Yes
_cons	-0.007 (0.082)	-0.102 (0.188)	-0.12 (0.083)	-0.015 (0.158)
Observations	19960	5196	19965	5191
R-squared	0.151	0.161	0.152	0.1

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

5.2.3. enterprise-size Heterogeneity

The size of an enterprise exerts a significant influence on the efficiency of innovation. For those enterprises that are of a sufficiently large scale, there is the possibility of meeting the needs of enterprise innovation in terms of capital investment to a certain extent. And enterprises with relatively low scale will face problems such as shortage of funds and low management efficiency. Therefore, this paper also analyzes the heterogeneity of enterprises of different sizes. The results of the analysis are shown in columns (3) and (4) of Table 7. The coefficients of the impact of ESG performance on the innovation efficiency of large-sized enterprises and small and medium-sized enterprises are 0.001 and 0.002 respectively, which are both significantly positive, but the impact on small and medium-sized enterprises is relatively low. There are several possible reasons for this result. First, compared to large enterprises, SMEs have high capital costs and limited human resources, while ESG practices require a certain amount of capital and talent investment. This may increase the operating costs of the enterprise and crowd out the funds that would otherwise be used for innovation and R&D. Second, SMEs tend to focus more on short-term profits. However, the long-term benefits brought by ESG are difficult to be realized in the short term, which leads SMEs to tend to invest their resources in areas that can generate quick returns and neglect their investment in ESG. Third, changes in the market environment will have a more significant impact on SMEs, making it more difficult for them to balance ESG and innovation investments as they face greater operational pressures.

6. Conclusions and recommendations

If enterprises ignore ESG principles in the pursuit of innovation, resulting in inefficient innovation, it will not only be difficult to meet the expectations of society for sustainable development, but also impede the realization of China's goal of high-quality development. In light of the aforementioned considerations, this paper seeks to investigate the influence of ESG performance on enterprise innovation efficiency, using A-share listed companies from 2011 to 2021 as the research sample. In order to provide some empirical evidence for improving enterprise innovation and realizing China's high-quality development.

This paper draws the following conclusions based on the study.:

First, the evidence suggests that good ESG performance has a significant positive impact on enterprise innovation efficiency. This conclusion remains robust even when the measurement method

of the explanatory variables is replaced and a one-period treatment is applied to the core explanatory variables. Second, the mechanism analysis shows that the promotion effect of ESG performance on enterprise innovation efficiency is mainly realized through improving enterprise information transparency and alleviating enterprise financing constraints. Third, the heterogeneity analysis based on region, industry, and enterprise size further indicates that the promotion effect of ESG performance on enterprises' innovation efficiency is relatively stronger in the eastern region and non-heavy pollution industries. The promotion effect is more pronounced in large enterprises than in small and medium-sized enterprises.

The findings presented in this study offer valuable insights that may inform strategies aimed at enhancing the innovative efficiency of enterprises in the context of China's pursuit of a green and high-quality economic development path:

First, enterprises should combine sustainable development with innovation strategies and adopt an integrated perspective for planning and development. Focusing on ESG performance helps identify and manage risks and seize innovation opportunities. Formulate specific ESG goals and plans, and integrate ESG concepts into the long-term development strategies of enterprises. At the same time, the government and related organizations should also strengthen policy guidance and support to jointly promote the sustainable and innovative development of enterprises.

Second, improving information transparency and easing enterprise financing constraints are both conducive to the enhancement of enterprise innovation efficiency. On the one hand, to enhance information transparency, it is imperative for enterprises to implement a robust ESG information disclosure framework. This will guarantee the comprehensive, precise, and punctual dissemination of pertinent data. The government should strengthen the regulation of information disclosure and clarify the ESG responsibilities and obligations of enterprises. Promote the establishment of a unified ESG evaluation system and standards to provide enterprises and investors with an objective and comparable basis for ESG evaluation. On the other hand, to alleviate financing constraints, enterprises should optimize their financing structure, improve their internal governance, and enhance their innovation ability and competitiveness. The government should broaden financing channels to provide enterprises with a better development environment and policy support.

Finally, ESG performance will have a differentiated impact on enterprise innovation efficiency. Furthermore, ESG performance plays a more significant role in promoting the innovation efficiency of enterprises in the eastern region. Therefore, enterprises in the eastern region should continue to deepen ESG practices and explore enterprise innovation models. They should share their experiences and technologies with enterprises in other regions to drive overall improvement and promote localized transformation and application by enterprises in other regions. It is recommended that the government implement a strategy of increased construction investment in pivotal sectors, including transportation, communications, and energy, within the central and western regions. Concurrently, it is advised that financial institutions be encouraged to extend enhanced credit support to enterprises situated within the aforementioned regions. It is imperative to develop a range of environmentally-conscious financial products that can cater to the diverse financing requirements of businesses. In addition, environmental, social and governance (ESG) performance has a stronger contribution to the innovation efficiency of enterprises in non-heavily polluting industries. Consequently, enterprises operating within industries that are significantly affected by pollution should prioritize ESG performance, allocate greater financial resources to environmental governance and pollution control, and facilitate technological innovation and transformation. The government needs to strengthen the regulation and constraints on enterprises in heavily polluting industries, as well as enhance industry guidance and training, and popularize successful experiences in non-polluting industries. Meanwhile, ESG performance has a relatively weak promotional effect on SMEs. Therefore, SMEs should integrate ESG concepts into enterprise strategies and daily operations, train and raise employee awareness, and increase investment in ESG. The government should provide SMEs with tax incentives, financial subsidies and technical support for ESG practices to reduce the transformation costs of SMEs.

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