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How Does Intelligent Manufacturing Affect the ESG Performance of Manufacturing Firms? Evidence from China

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Abstract: It is no longer possible for China's economy to grow by relying on the rapid expansion of manufacturing. On the one hand, China's previous rough manufacturing development pattern seriously harmed the environment. On the other hand, China's manufacturing productivity and international competitiveness have decreased as a result of the disappearance of demographic dividends and growing labor costs. China's manufacturing firms must simultaneously increase productivity while lowering environmental pollution. This study, which takes *intelligent manufacturing pilot demonstration projects* as a quasi-natural experiment, investigates the impact of intelligent manufacturing (IM) on environmental, social and governance (ESG) performance using data from 2149 listed manufacturing firms in China from 2009 to 2021. The results indicate that ESG performance of the listed firms could be improved using IM. The heterogeneity test reveals that IM in non-state-owned firms helps to improve ESG performance at the 1% significance level, while the effect is not significant in state-owned firms. Moreover, the effect in eastern China is significant at the 1% level and at the 5% level in western China, but not significant in central and northeastern China. The two channels through which IM improves corporate ESG performance are promoting innovation investment and improving the quality of the information environment. This study also verifies that both internal and external supervision could strengthen the positive impact of IM on corporate ESG performance, which provides empirical evidence for strengthening the supervision of manufacturing firms. The conclusions of the study reveal the internal force of manufacturing firms to improve ESG performance and also provide theoretical support for their implementation of IM projects.

Keywords: intelligent manufacturing; environmental; social and governance performance; innovation investment; information environment; supervision

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1. Introduction

China has developed a complete industrial system over the past 40 years, which has contributed greatly to economic development [1]. It is widely believed that this achievement was obtained at the expense of environmental pollution [2]. How to deal with environmental problems has become a challenge for China's manufacturing industry. China is currently in a critical period of economic transformation. Manufacturing firms face the dual task of improving productivity and reducing environmental pollution. Therefore, the Chinese government and other stakeholders attach great importance to the environmental, social and governance (ESG) practices of manufacturing firms [3].

ESG practices could help firms improve productivity [4], profitability [5], reputation [6] and market value [7], alleviate financing constraints [8], reduce financial risk [9] and stock price volatility risk [10], etc. In September 2018, the China Securities Regulatory Commission (CSRC) revised the *Code of Corporate Governance for Listed Companies* to establish a basic framework for listed firms to disclose information on ESG practices. However, some firms have inadequate ESG practice capabilities and incur significant costs in their ESG practices, which reduces their incentive to improve ESG performance. As a result, the ESG practices of these companies are less efficient under the goal of maximizing shareholders'

interests. Therefore, in addition to improving corporate ESG performance through external supervision, it is critical to improve ESG practice capabilities and strengthen internal driving forces.

With the disappearance of the demographic dividend, the number of manual workers in China shows a decreasing trend [11]. Labor shortage and recruitment difficulties in many manufacturing firms are becoming serious. The rising labor costs of manufacturing firms have led to loss of international comparative advantage. In order to alleviate labor shortage and reduce production and operation costs, some manufacturing firms have implemented IM projects. Artificial intelligence (AI) and Big Data technologies provide opportunities for IM [12]. AI is the core engine of the fourth industrial revolution. IM is based on AI technologies, which is a process of transformation of traditional industries using advanced intelligent technology systems [13]. AI technologies run through every link in the design, production and service [14], which helps to reduce manufacturing-related costs and improve efficiency at all stages of the product life-cycle. In addition, AI, the Internet of Things, 5G and big data technologies as key elements of IM can help manufacturing firms improve green total factor productivity (total factor productivity of environmental factors, energy, and other factors) by replacing laborers [15].

Previous studies have explored the influencing factors [16–18], challenges [19,20] and upgrading pathways [21,22] of IM, the impact of IM on corporate production costs [23], productivity [24,25], business processes [26], financial performance [27,28], and innovation [29,30], etc. Studies on factors influencing corporate ESG performance have focused on ownership structure [31,32], board structure [33], pledges of controlling shareholders [34], M&A activity [35], CEO payment [36], CEO confidence [37], CSR committee [38], executive incentive [39], etc.

Unfortunately, few studies have explored the impact of IM on corporate ESG performance. As an important strategic action for manufacturing firms, does IM affect corporate ESG performance? How does it affect ESG performance? Is the impact of IM on corporate ESG performance influenced by other factors, such as corporate supervision? Studying these issues is important to improve corporate ESG performance, but existing research is inadequate. From the perspective of corporate innovation theory, IM is associated with product innovation, technological innovation, organizational innovation and resource allocation innovation. It usually increases the innovation inputs and outputs of the firm [40]. From the perspective of principal agent theory, IM helps to improve the quality of the corporate information environment and improve corporate transparency [41]. All of these factors are likely to positively impact corporate ESG practices. Therefore, IM may be a powerful internal force to improve corporate ESG performance, which is the subject of this study.

This study enriches the research literature on IM and ESG performance. There are three main contributions. Firstly, we explore the mechanisms by which IM impacts the ESG performance of manufacturing firms. IM is a fundamental change in the way manufacturing firms produce and operate, which provides an internal force for improving corporate ESG performance. It balances shareholders' interests and ESG performance well. Secondly, we also verify that IM not only improves the ESG performance of the firms themselves, but also has a positive impact on the ESG performance of their holding firms. This suggests that IM can be vertically integrated to form an innovation network through the exchange of information, resources and technologies between firms and their holding firms to achieve synergistic development of the conglomerate. Thirdly, we identify corporate innovation investment and the corporate information environment as two channels through which IM impacts corporate ESG performance and verify the positive effects of internal and external supervision on corporate ESG performance.

2. Literature Review and Hypotheses Development

2.1. IM and ESG Performance

Previous studies have shown that IM can help firms obtain sustainable growth. Yin et al. used the PSR model to measure the level of green innovation in manufacturing firms and verified that the adoption of digital technologies such as AI by firms can promote green innovation and have a positive effect on their sustainable development [42]. Yang et al. proposed that IM is an important strategic option for achieving green innovation. They examined the impact of IM on green innovation performance using the dynamic spatial lag model (DSAR), mediating effect model and moderating effect model. IM improved the efficiency of green innovation through the "technology facilitation effect" and "cost reduction effect" [43]. Zhong et al. used data on Chinese listed firms in Shanghai and Shenzhen A-shares from 2010–2020 and found that corporate digital transformation can enhance the strengths of internal control, strategic management and innovation capabilities, which in turn improve ESG performance [44].

Modern corporate governance theory and stakeholder theory require firms to be responsible not only to shareholders, but also to creditors, employees, suppliers and customers, governments, communities, and the environment [45–47]. In other words, firms should focus on external governance, pay more attention to stakeholders and maximize the overall interests of stakeholders. However, ESG practices damage firm value by consuming resources, increasing operating costs and reducing profitability in the short term [48]. This may negatively impact decisions related to corporate ESG practices, and managers tend to reduce their investment in ESG practices. To promote ESG practices, governments have successively strengthened corporate regulation and mandated ESG disclosure [49,50]. In addition to governments, norms set by professional organizations, industry associations and other sectors are also sources of mandatory pressure [51]. Firms succumb to pressure to disclose ESG information, but they do not necessarily improve ESG performance. For example, some manufacturing firms have more bargaining power with local governments because of the large number of jobs they provide. They have more opportunities to be exempted from regional regulations and may lack internal force to improve ESG performance [52].

IM provides an internal force for manufacturing firms to improve ESG performance. Firstly, IM is an intelligent manufacturing system that integrates perception, analysis, decision making and execution on the basis of digitization, automation and intelligence. It is dedicated to promoting the integration of new-generation information technology, AI technology and traditional production technology [14]. With advanced intelligent monitoring systems and infrared sensing technologies, IM firms can quickly lock the pollution sources in the production process and realize pollution control from end to end. Secondly, IM firms can achieve accurate production, sales and inventory management through intelligent systems, thus forming a high-quality co-creation network with employees, customers, suppliers, distributors, etc. [53]. This not only improves the relationship between firms and related subjects upstream and downstream of the industry chain, but also reduces the transaction costs and corporate governance costs. Thirdly, all elements in the production stage can be integrated into a tightly coordinated production process through digital methods in the intelligent manufacturing system. This can produce smarter manufacturing planning and precise production control [54], reduce irrationality and information asymmetry in managers' decision making, improve decision-making efficiency [55], and thus improve corporate governance. Accordingly, hypothesis 1 is proposed.

Hypothesis 1. *IM provides internal force for manufacturing firms to improve ESG performance.*

2.2. IM, Innovation Investment and ESG Performance

IM helps to improve corporate productivity and promote innovation [56,57], such as innovation in products, technologies and even business models. Digital platforms provide technology and knowledge for innovation [58]. Digital technology enables firms to

better communicate with stakeholders, achieve greater information search at lower cost, quickly identify innovation opportunities and access innovation resources [59], and gain competitive advantage [60]. IM promotes not only innovation inputs but also innovation outputs for firms [40]. Continuous innovation inputs and outputs ensure that firms obtain stable technological progress, which not only promotes the sustainable development of firms, but also promotes society-wide technological progress through external effects.

Different from traditional manufacturing technologies, the characteristics of IM are shown as follows [61]. Firstly, AI and digital technologies are used to realign the design, production and management processes to achieve a dynamic response to demand and supply. Secondly, internet platforms are used to achieve deep interaction with consumers and flexible production lines are used to provide consumers with personalized products. Thirdly, internal and external coordination and flat management are emphasized to adapt to the ever-changing external environment. Fourthly, technological innovation, organizational innovation and management innovation are carried out continuously as a learning organization. As can be seen, IM is not simply the purchase of intelligent production equipment, but a fundamental innovation in the entire production and operation process to achieve the intelligence of the whole product life cycle.

Innovation is an important way to solve environmental problems [62]. New technologies and techniques help to improve the productivity of firms, reduce their consumption of energy [63] and pollution to the environment, and ultimately improve environmental performance [64]. Through personalized and customized production changes, IM firms meet the diverse needs of consumers, improve the level of consumer utility, increase the market share of their products and achieve Pareto optimization for the whole society. In other words, firms could better meet the needs of their stakeholders through innovation. The flat organizational structure brought about by IM makes the concept of strict hierarchy fade away. Firms increasingly focus on equality and openness, resulting in more efficient information transfer, lower decision costs and more effective execution of corporate strategy [65]. Accordingly, hypothesis 2 is proposed.

Hypothesis 2. *IM improves corporate ESG performance through the channel of stimulating corporate innovation investment*.

2.3. IM, Information Environment and ESG Performance

IM digitizes work scenarios, enables real-time data collection and analysis, transforms them into user-friendly visual interfaces and makes informed decisions through collaboration with humans [66]. It helps firms improve operational efficiency and reduce management costs by leveraging the advantages of digital platforms for immediate information transfer [67], enabling accurate tracking of the entire business process [68], accelerating corporate information integration and improving information transparency [41].

In the modern industrial system, manufacturing firms can establish horizontal network relationships with partners through the supply chain, but there are still some barriers to intellectual property and knowledge sharing [69]. A high-quality information environment benefits both information users and firms. Conversely, ambiguous and complex information environments undermine investors' trust in firms [70]. The industrial internet is an integral part of an intelligent manufacturing system, and the sharing and networking of data and corporate resources is the essential embodiment of IM [71]. An intelligent manufacturing system saves the data related to production and operation in a data platform, forming digital copies and presenting them to the data requester [72], which can effectively reduce the supervision costs of the firms. As the quality of the corporate information environment improves, it becomes easier for relevant interest groups to track corporate behavior. Thus, management's opportunistic behavior can be more strongly restrained [73]. This helps reduce management corruption and improve corporate governance. In a nutshell, information sharing among stakeholders can improve their trust in firms, reduce transaction costs and strengthen their cooperation with firms.

Firms with higher-quality information environments facilitate stakeholder access to information about corporate ESG practices. Higher ESG performance usually means higher financial performance [74], higher reputation [6] and higher market value [7]. These firms with higher ESG performance face fewer financing constraints [8]. Institutional investors and banks prefer to invest in firms with higher ESG performance [75]. As a result, firms with higher-quality information environments have a greater willingness to improve their ESG performance. Accordingly, hypothesis 3 is proposed.

Hypothesis 3. *IM improves corporate ESG performance through the channel of improving the quality of the corporate information environment*.

3. Research Design

3.1. Econometric Model

To test the impact of IM on corporate ESG performance, drawing on Beck et al. [76], the following multiple-period DID model was constructed. The *p*-value of the Hausman test is less than 0.01, indicate that the fixed-effect model should be selected.

$$ESG_{it} = \alpha_0 + \alpha_1 IM_{it} + \sum \alpha_i Control_{it} + \lambda_i + \delta_t + \varepsilon_{it} \quad (1)$$

The subscript i and t denote firm and year, ESG_{it} denotes corporate ESG performance. IM_{it} is a dummy variable indicating intelligent manufacturing, $IM = Treat \cdot Time$. If firm i is listed as a IM firm by the Ministry of Industry and Information Technology of China (MIITC) in year t, then IM = 1 ($Treat$ = 1, $Time$ = 1) in that year and in subsequent year. Before that, IM = 0 ($Treat$ = 1, $Time$ = 0). The firms that never implemented IM projects have two states, IM = 0 ($Treat$ = 0, $Time$ = 0) and IM = 0 ($Treat$ = 0, $Time$ = 1). $Control_{it}$ denotes control variables, λ_i and δ_t denote firm and time fixed effect, and ε_{it} denotes the error term.

3.2. Variable Measurement and Description

3.2.1. Dependent Variable

Corporate ESG performance (ESG) was the dependent variable. The ESG rating index is widely used for the quantitative evaluation of the ESG performance of Chinese firms [77,78]. We used the Huazheng ESG rating index (HESG) to measure corporate ESG performance because it covers all A-share listed firms and has a long time span. It is composed of 3 primary indicators, 14 secondary indicators, 26 tertiary indicators and over 130 underlying indicators. In addition, the Bloomberg ESG evaluation index (BESG) was used for the robustness test [79]. Bloomberg not only provides an ESG evaluation index, but also E, S and G evaluation results. It is a more comprehensive evaluation index, but currently only covers about 1000 Chinese listed firms. Compared with HESG, BESG has more missing data.

3.2.2. Independent Variable

Intelligent manufacturing (IM) was the independent variable. From 2015 to 2018, the Ministry of Industry and Information Technology of China released the *List of Intelligent Manufacturing Pilot Demonstration Projects* every year. Drawing on Liu et al. [27] and Qu et al. [80], we treated this as a quasi-natural experiment and identified IM firms from the list. Among them, some IM projects were implemented by the listed firms themselves and some were implemented by subsidiaries held by the listed firms. Excluding duplicate projects, we found a total of 124 firms that implemented IM projects.

3.2.3. Mediating Variables

Corporate innovation investment (R&D) and the corporate information environment (INFORM) were the mediating variables. According to the literature review, IM firms invest more in innovation and the information environment, which improves corporate ESG performance. Drawing on previous research, the logarithm of the amount of corporate

R&D expenditure [81,82] was used to measure the corporate innovation investment. The information disclosure ratings of listed firms disclosed by the Shanghai Stock Exchange and Shenzhen Stock Exchange [83] was used to measure the quality of the corporate information environment, with A as a rating of 4, B as a rating of 3, C as a rating of 2, and D as a rating of 1.

3.2.4. Control Variables

According to the previous literature, some macro- and micro-factors also impact corporate ESG performance. Micro-control variables include corporate size (SIZE), financial leverage (LEV), profitability (ROA), growth capacity (GROWTH), equity concentration (TOP1), corporate age (*AGE*), and Tobin's Q-value (TOBIN_Q) [31,84–88]. Macro-control variables include regional openness (OPEN), government fiscal spending (GOV), economic development (GDP) and the relative development of the tertiary sector (INDUSTRY) [79,89–91]. The variables are defined in Table 1.

Table 1. Variable definitions.

Variable	Name	Calculation/Value
HESG	Corporate ESG performance	Huazheng ESG rating index, taking values from 1 to 9, where AAA = 9, AA = 8, A = 7, BBB = 6, BB = 5, B = 4, CCC = 3, CC = 2, C = 1
BESG	Corporate ESG performance	Bloomberg ESG evaluation index
E	Corporate E performance	Bloomberg E evaluation index
S	Corporate S performance	Bloomberg S evaluation index
G	Corporate G performance	Bloomberg G evaluation index
IM	Intelligent manufacturing	IM = 1 if the firm has implemented intelligent manufacturing during the year, otherwise IM = 0
R&D	Corporate innovation investment	R&D = ln(corporate R&D expenditure)
INFORM	Quality of corporate information environment	Corporate disclosure ratings published by Shanghai Stock Exchange and Shenzhen Stock Exchange, taking values from 1 to 4, where A = 4, B = 3, C = 2, D = 1
SIZE	Corporate size	ln(corporate assets)
LEV	Financial leverage	Total liabilities/total assets
ROA	Corporate profitability	Net profit/total assets
GROWTH	Corporate growth capacity	(operating income in year t—operating income in year t − 1) operating income in year t − 1
TOP1	Corporate equity concentration	Percentage of shareholding of the largest shareholder
AGE	Corporate age	Current year—year of establishment
TOBIN_Q	Tobin Q value	Stock market value total assets
OPEN	Regional openness	Regional general public budget expenditure regional GDP
GOV	Regional government fiscal spending	Regional general public budget expenditure regional GDP
GDP	Regional GDP	ln(regional GDP)
INDUSTRY	Relative development of the regional tertiary sector	Value added of regional tertiary industry regional GDP
INDIRECTOR	Percentage of independent directors	Number of independent directors total number of directors
FUND	Fund shareholding ratio	Shareholding ratio of the firm by the fund
ANALYST	Analyst focus	ln(the number of analyst teams following the firm in the current year + 1)
REPORT	Report disclosure	ln(number of research reports analyzing the firm in the current year + 1)

Note: Region means the province where the firm is located.

3.3. Data Sources

This paper selected 2149 Chinese A-share listed manufacturing firms from 2009–2021 as the research sample. The ESG rating index of Chinese listed firms can be traced back to as early as 2009. *HESG* data came from the Wind database. *BESG*, *E*, *S* and *G* data came from the Bloomberg database. *IM* data were compiled by the authors based on the *List of Intelligent Manufacturing Pilot Demonstration Projects* released by the Ministry of Industry and Information Technology of China from 2015–2018. Other corporate-related micro-data came from the CSMAR database. Macro-data came from the *China Statistical Yearbook* and provincial statistical yearbooks. The sample was determined based on the following criteria: (1) exclusion of ST and *ST firms; (2) exclusion of firms listed for less than 1 year; (3) exclusion of firms with missing data on variables. Finally, all continuous variables were winsorized at the 1% and 99% levels.

4. Results

4.1. Descriptive Statistics

Table 2 shows the results of descriptive statistics; the lowest, highest and mean values of HESG are 4, 8 and 6.389, and the standard deviation is 0.973. The lowest, highest and mean values of BESG are 9.091, 45.041 and 21.145, and the standard deviation is 6.758. This indicates that most of the listed firms' ESG performance is in the middle to upper level, and there are some differences between the sample firms. The core independent variable *IM* is a dummy variable with a mean value of 0.038, indicating that most listed manufacturing firms in China are not IM firms. In addition, the average level of ESG performance of state-owned firms is higher than that of non-state-owned firms, indicating that state-owned firms pay more attention to ESG practices.

Table 2. Descriptive statistics for all variables.

Panel A					
Variable	**Obs**	**Mean**	**D.**	**Min**	**Max**
HESG	15,669	6.389	0.973	4	8
BESG	4254	21.145	6.758	9.091	45.041
E	3754	11.820	8.152	2.326	45.736
S	4169	23.646	8.938	7.017	56.140
G	4254	44.299	5.030	33.929	57.143
IM	15,669	0.038	0.192	0	1
R&D	15,669	18.033	1.364	5.094	25.025
INFORM	15,669	2.671	1.003	1	4
SIZE	15,669	21.989	1.136	20.070	25.585
LEV	15,669	0.366	0.181	0.049	0.769
ROA	15,669	0.051	0.053	−0.154	0.207
GROWTH	15,669	0.220	0.477	−0.555	2.878
TOP1	15,669	0.342	0.139	0.096	0.722
AGE	15,669	7.513	6.490	0	25
TOBIN_Q	15,669	2.107	1.222	0.889	7.820
OPEN	15,669	9.642	1.357	5.761	11.463
GOV	15,669	8.919	0.522	7.438	9.810
GDP	15,669	10.672	0.690	8.593	11.731
INDUSTRY	15,669	0.529	0.103	0.357	0.837
INDIRECTOR	15,669	0.376	0.053	0.333	0.571
FUND	15,669	0.094	0.143	0	0.701
ANALYST	15,669	1.545	1.189	0	3.850
REPORT	15,669	1.891	1.466	0	4.745
Panel B					
Variable	**Obs**	**Mean**	**D.**	**Min**	**Max**
HESG_state-owned firms	3802	6.826	1.047	4	8
HESG_non-state-owned firms	11,867	6.249	0.905	4	8

4.2. Baseline Regression Results

The regression results are shown in Table 3. In Table 3, model (1) does not contain any control variables, model (2) contains corporate-related micro-control variables, model (3) further contains macro-control variables, model (4) excludes the sample of IM projects only implemented by subsidiaries held by listed firms, and model (5) excludes the sample of IM projects implemented by the listed firms themselves. The regression coefficients of IM in models (1)–(5) are all significantly positive, indicating that IM projects, either implemented by listed firms themselves or by their holding subsidiaries, could significantly improve corporate ESG performance. Thus, hypothesis 1 was verified.

Table 3. Baseline regression results.

Variable	(1) HESG	(2) HESG	(3) HESG	(4) HESG	(5) HESG
IM	0.222 ***	0.208 ***	0.207 ***	0.187 ***	0.292 ***
	(0.043)	(0.043)	(0.043)	(0.047)	(0.092)
SIZE		0.214 ***	0.220 ***	0.222 ***	0.220 ***
		(0.022)	(0.022)	(0.022)	(0.022)
LEV		−0.484 ***	−0.470 ***	−0.470 ***	−0.464 ***
		(0.077)	(0.077)	(0.077)	(0.079)
ROA		0.881 ***	0.864 ***	0.862 ***	0.804 ***
		(0.177)	(0.177)	(0.178)	(0.181)
GROWTH		−0.012	−0.012	−0.012	−0.015
		(0.016)	(0.016)	(0.016)	(0.016)
TOP1		0.730 ***	0.699 ***	0.701 ***	0.720 ***
		(0.126)	(0.127)	(0.128)	(0.133)
AGE		−0.076 **	−0.077 **	−0.079 ***	−0.072 **
		(0.031)	(0.031)	(0.031)	(0.034)
TOBIN_Q		0.016 **	0.015 **	0.016 **	0.017 **
		(0.007)	(0.007)	(0.007)	(0.007)
OPEN			0.118 **	0.117 **	0.111 **
			(0.048)	(0.049)	(0.052)
GOV			−0.295 ***	−0.289 ***	−0.272 **
			(0.103)	(0.104)	(0.107)
GDP			0.118	0.104	0.164
			(0.131)	(0.131)	(0.141)
INDUSTRY			−0.372	−0.377	−0.626 *
			(0.298)	(0.306)	(0.323)
_CONS	6.380 ***	2.109 ***	2.417 **	2.485 **	1.840
	(0.006)	(0.528)	(1.066)	(1.073)	(1.154)
FIRM FIXED EFFECT	Yes	Yes	Yes	Yes	Yes
TIME FIXED EFFECT	Yes	Yes	Yes	Yes	Yes
N	15,669	15,669	15,669	15,440	14,707
R^2	0.547	0.556	0.556	0.553	0.545
F	26.731 ***	27.449 ***	20.343 ***	19.471 ***	17.526 ***

Note: Robust standard errors are in parentheses; ***, **, and * indicate significant levels at 1%, 5%, and 10%, respectively.

Among the control variables, corporate size (SIZE), corporate profitability (ROA), Tobin's Q (TOBIN_Q) and corporate equity concentration (TOP1) have a significant positive impact on ESG performance, while corporate leverage (LEV) and corporate age (AGE) have a significant negative impact on ESG performance. These results are consistent with previous research [31,33,39]. The possible reasons are as follows. Firstly, listed firms with large size, high profit and high stock price generally have more funds to support their ESG practices. Secondly, the more centralized corporate decision-making power is, the better it is at overcoming the hindrance of corporate ESG practices. Thirdly, firms with higher financial leverage tend to face greater financial pressures, so it is more difficult for them to invest in ESG practices. Fourthly, the older the corporate age, the stronger the firm's reliance on traditional ways of doing business and the more difficult it is to make rapid changes in ESG practices.

Regional openness (OPEN) has a significant positive impact on ESG performance, indicating that firms engaged in international trade tend to pay more attention to ESG practices in order to gain external recognition. Regional fiscal expenditure (GOV) has a significant negative impact on ESG performance, mainly because a large portion of local policy fiscal expenditure comes from local government debt financing, which squeezes out corporate financing and raises corporate financing costs, thus reducing corporate investment in ESG practices.

4.3. Robustness Test

4.3.1. Parallel Trend Test

The application of the DID method requires that the treatment and control groups satisfy the parallel trend assumption: there is no significant difference in ESG performance between the treatment and control groups before the event. For this purpose, the estimating equation was constructed as follows.

$$ESG_{it} = \alpha_0 + \sum_{j=-6}^{6} \alpha_j D_{i,t+j} + \sum \beta_i Control_{it} + \lambda_i + \delta_t + \varepsilon_{it} \quad (2)$$

The difference between Equations (1) and (2) is that we constructed the dummy variable D. If the firm implemented the IM project in that year, $D = 1$, otherwise $D = 0$.

Figure 1 shows the results of the parallel trend test for the first six years and the last six years of a firm's implementation of an IM project. The regression coefficients α_{-6} to α_{-1} are all insignificant, implying that there is no significant difference of ESG performance between the treatment and control groups before the implementation of the IM project. After the implementation of the IM project, the regression coefficients α_3 to α_5 are all significantly positive, indicating that IM can significantly improve corporate ESG performance. The results in Figure 1 show that the treatment and control groups satisfy the parallel trend assumption.

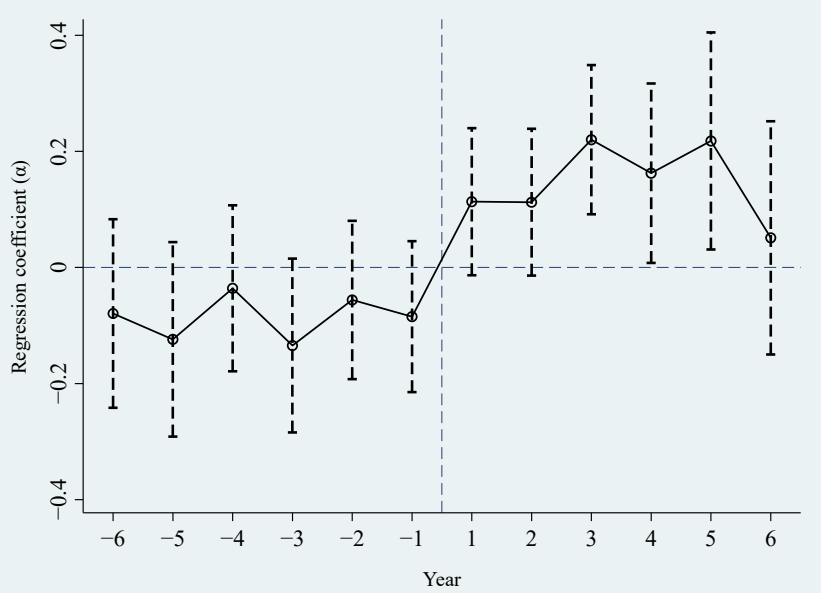


Figure 1. Parallel trend test of the impact of IM on HESG.

4.3.2. PSM—DID

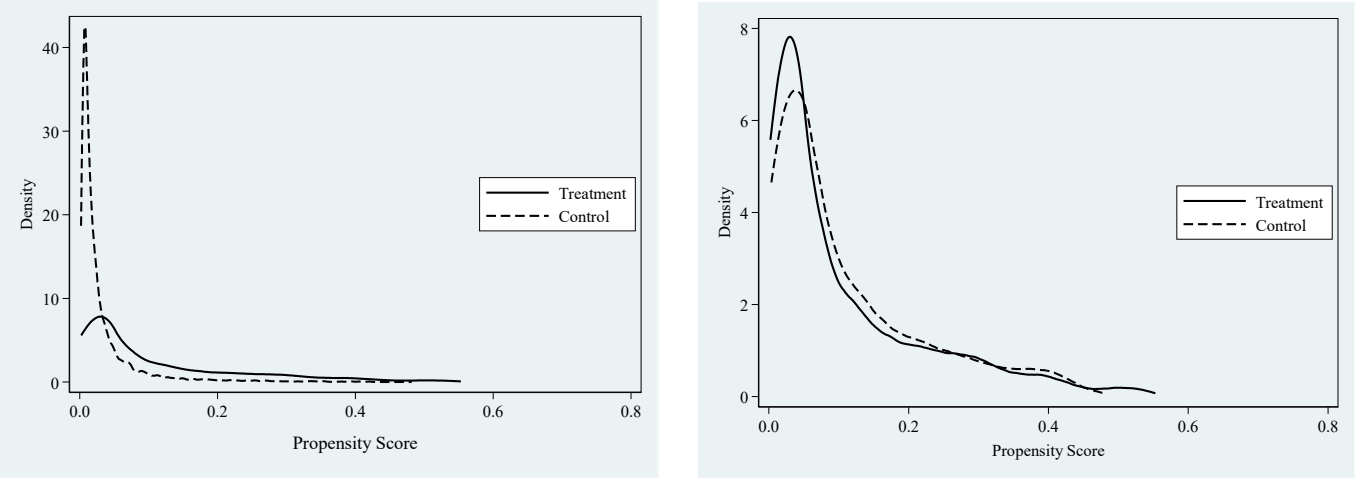
Whether a manufacturing firm implements an IM project or not is not completely random or exogenous, which affects the comparability between the treatment and control groups. Therefore, the propensity score matching (PSM) method was used to obtain a comparable control group. Specifically, we used a non-alternative 1-to-1 nearest neighbor matching method to obtain comparable control groups using firm characteristic variables as the matching criteria.

The results in Table 4 show that the values of standard deviation of the variables after matching are all less than 10%, indicating that the samples after PSM pass the balance test. Meanwhile, t-statistics of the variables after matching are all insignificant, indicating that there is no significant difference between the treatment and control groups for the matched variables after matching.

Table 4. Balance test.

Variable	Unmatched	Mean		%Bias	%Reduct	*t*-Test	
	Matched	Treat	Control		|Bias|	t	p > |t|
SIZE	U	23.472	21.929	129.4		33.8	0
	M	23.418	23.405	1.1	99.1	0.17	0.862
LEV	U	0.487	0.361	73.1		16.91	0
	M	0.483	0.484	−0.6	99.2	−0.1	0.92
ROA	U	0.046	0.051	−9.9		−2.29	0.022
	M	0.046	0.049	−6.4	35.1	−1.11	0.269
GROWTH	U	0.206	0.221	−3.4		−0.74	0.457
	M	0.210	0.217	−1.6	52.2	−0.28	0.781
TOP1	U	0.338	0.342	−3.1		−0.75	0.455
	M	0.342	0.343	−0.9	69.9	−0.15	0.878
AGE	U	13.394	7.278	89.3		23.04	0
	M	13.131	13.457	−4.8	94.7	−0.78	0.436
TOBIN_Q	U	1.750	2.121	−31.7		−7.3	0
	M	1.760	1.787	−2.3	92.7	−0.4	0.689

Figure 2a shows the kernel density function plot before matching. Figure 2b shows the kernel density function plot after matching. Comparing Figure 2a,b, we find that the treatment and control groups appear significantly close to each other after one-to-one matching. This indicates that the samples obtained using PSM are valid and ensures the reliability of the estimation results in this paper.



(**a**) Before matching (**b**) After matching

Figure 2. Kernel density distribution of scores.

Using the 15,085 new samples obtained after matching, the new regression results are shown in Model (1) in Table 5. The regression coefficient of *IM* is still significantly positive, and there is no significant change in the magnitude and significant level of the regression coefficient, indicating that the regression results are credible.

4.3.3. Replace the Evaluation Index of ESG Performance

The Bloomberg ESG evaluation index and the E, S and G sub-evaluation indices were used to replace the Huazheng ESG rating index. The regression results are shown in models (2)–(5) in Table 5. The regression coefficients of IM remained significantly positive, and the significance of coefficients did not change significantly compared with model (3) in Table 3, indicating that the results of the baseline regression are robust.

Table 5. DID regression results after PSM.

Variable	(1) HESG	(2) BESG	(3) E	(4) S	(5) G
IM	0.209 ***	1.937 ***	3.637 ***	1.250 ***	0.752 ***
	(0.043)	(0.337)	(0.529)	(0.439)	(0.242)
CONTROL	Yes	Yes	Yes	Yes	Yes
_CONS	Yes	Yes	Yes	Yes	Yes
FIRM FIXED EFFECT	Yes	Yes	Yes	Yes	Yes
TIME FIXED EFFECT	Yes	Yes	Yes	Yes	Yes
N	15,085	4220	3729	4140	4220
R^2	0.561	0.746	0.676	0.721	0.759
F	19.683 ***	10.037 ***	7.823 ***	8.434 ***	9.777 ***

Note: The samples used in Table 5 are after 1-to-1 nearest neighbor matching, with the same below. Robust standard errors are in parentheses; *** indicate significant levels at 1%.

4.3.4. Placebo Test

Drawing on Li et al. [92] and Cantoni et al. [93], a placebo test was conducted to test whether the improvement of corporate ESG performance was caused by other random factors. We randomly generated the treatment group, repeated the regression 500 times, and tallied the t-values of the regression coefficients of the IM. Then, kernel density plots of the t-values of the regression coefficients of the IM were made and compared with the t-value of the regression coefficients of the IM in model (3) of Table 3. Observing Figure 3, the t-values of all regressions are smaller than the t-value (4.84) in model (3) of Table 3, indicating that the impact of IM on ESG performance is relatively robust and does contribute to the improvement of corporate ESG performance.

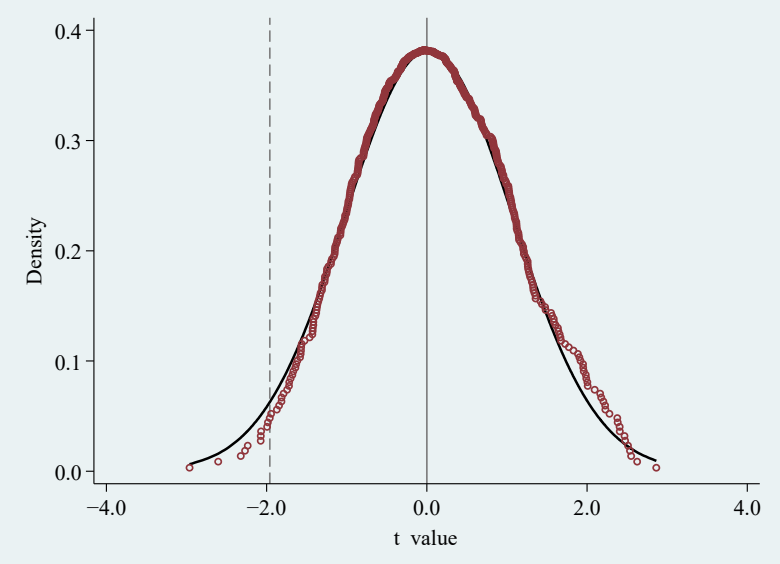


Figure 3. t-value of regression of IM on ESG performance.

5. Heterogeneity Test

5.1. Micro-Heterogeneity: Corporate Ownership

State-owned firms and non-state-owned firms face different business environments and have different decision-making mechanisms in China [94]. Compared to state-owned firms, non-state-owned firms face stricter financing constraints [95] and fiercer market competition [96]. Non-state-owned firms pursue profit as the first goal of business operation. State-owned firms not only pursue profit but also take on more public service functions. They are under more pressure to fulfill their social responsibilities [97]. The mean ESG performance of state-owned firms is 6.83 and the mean ESG performance of

non-state-owned firms is 6.25. This result is consistent with Zahid et al. [98]. The difference between the two is significant, indicating that state-owned firms pay more attention to ESG practices compared to non-state-owned firms. If the impact of IM on corporate ESG performance is heterogeneous between state-owned and non-state-owned firms, this helps the government develop targeted support policies to help manufacturing firms improve their ESG performance.

The regression results are shown in Table 6. In Table 6, model (1) is the regression result for state-owned firms and model (2) is for non-state-owned firms. We found that IM did not impact ESG performance in state-owned firms, while significantly improving ESG performance in non-state-owned firms. This finding is generally consistent with Fang's study. They found that the impact of corporate digitization on ESG performance was more pronounced for non-politically connected firms in China [99]. This indicates that non-state-owned firms have greater potential to improve ESG performance relative to state-owned firms. State-owned firms do not show significant differences in ESG performance whether they implement IM projects or not. Therefore, this study argues that focusing on promoting the implementation of IM projects in non-state-owned manufacturing firms can be more effective in improving the overall ESG performance of China's manufacturing industry.

Table 6. Sub-sample regression of companies by ownership and location.

Variable	(1) HESG	(2) HESG	(3) HESG	(4) HESG	(5) HESG	(6) HESG
IM_state-owned firms	0.068 (0.058)					
IM_non-state-owned firms		0.226 *** (0.065)				
IM_eastern region firms			0.226 *** (0.055)			
IM_central region firms				0.116 (0.105)		
IM_western region firms					0.247 ** (0.104)	
IM_northeastern region firms						0.130 (0.288)
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes
_CONS	Yes	Yes	Yes	Yes	Yes	Yes
FIRM FIXED EFFECT	Yes	Yes	Yes	Yes	Yes	Yes
TIME FIXED EFFECT	Yes	Yes	Yes	Yes	Yes	Yes
N	3732	11,321	10,895	2090	1609	484
R^2	0.644	0.500	0.562	0.526	0.585	0.621
F	2.744 ***	15.046 ***	13.417 ***	2.800 ***	5.545 ***	2.392 ***

Notes: Robust standard errors are in parentheses; *** and ** indicate significant levels at 1% and 5%.

5.2. Macro-Heterogeneity: Corporate Location

China is a country comprising 34 administrative regions. It is a vast country with significant differences in resource endowments, industry characteristics and government policies across geographic regions [100,101]. Corporate ESG practices may be influenced by regional differences [31]. For example, if the local government enacts stricter environmental regulations, firms' environmental pollution practices will be more constrained [102]. According to the division method of the National Bureau of Statistics of China, we divided China into four regions: eastern region, central region, western region and northeastern region. The regression was conducted for each of the four regions. This helps us have a more comprehensive understanding of the conditions under which IM affects corporate ESG performance and provides empirical lessons for local governments to adjust their industrial policies.

The regression results are shown in Table 6. In Table 6, models (3)–(6) show the results for the eastern, central, western and northeastern regions, respectively. IM significantly

improved corporate ESG performance in the eastern and western regions, while it had no significant impact of IM on corporate ESG performance in the central and northeastern regions. The eastern region has a more rational industrial structure, closer cooperation in the industrial chain and higher industrial value added [103]. The western region focuses on the development of agriculture and tourism industries [104], and local governments and entrepreneurs are more aware of environmental protection. As a result, firms in eastern and western China significantly improved their ESG performance when implementing IM projects. The central and northeastern regions mainly develop high-energy-consumption and high-pollution industries such as energy extraction and processing, heavy equipment manufacturing, etc. [105]. Even if the firms in these regions implement IM projects, it is difficult to improve ESG performance in the short term.

6. Further Analysis

6.1. Impact Channels: Innovation Investment and Information Environment

To investigate the channels through which IM impacts corporate ESG performance, we constructed the following regression model.

$$ESG_{it} = \alpha_0 + \alpha_1 IM_{it} + \sum \alpha_i Control_{it} + \lambda_i + \delta_t + \varepsilon_{it} \quad (3)$$

$$Mediating_{it} = \beta_0 + \beta_1 IM_{it} + \sum \beta_i Control_{it} + \lambda_i + \delta_t + \varepsilon_{it} \quad (4)$$

$$ESG_{it} = \phi_0 + \phi_1 IM_{it} + \phi_2 Mediating_{it} + \sum \phi_i Control_{it} + \lambda_i + \delta_t + \varepsilon_{it} \quad (5)$$

Equation (3) is the same as Equation (1). The subscript i and t denote firm and year. ESG_{it} denotes corporate ESG performance. IM_{it} is a dummy variable indicating intelligent manufacturing. $Mediating_{it}$ denotes mediating variables, which refers to corporate innovation investment (R&D) or corporate information environment quality (INFORM) depending on different impact channels. $Control_{it}$ denotes control variables, and λ_i and δ_t denote firm and time fixed effect, respectively. ε_{it} denotes the error term.

The regression results are shown in Table 7. The regression coefficient of IM in model (1) is significantly positive and the regression coefficient of R&D in model (2) is significantly positive, indicating that IM could improve corporate ESG performance through the channel of promoting corporate innovation investment. Thus, hypothesis 2 is verified. The regression coefficient of IM in model (3) is significantly positive, and the regression coefficient of INFORM in model (4) is significantly positive, indicating that IM could improve corporate ESG performance through the channel of improving the quality of the corporate information environment. Thus, hypothesis 3 is verified.

Table 7. Impact channels of IM on ESG performance.

Variable	(1) R&D	(2) HESG	(3) INFORM	(4) HESG
IM	0.148 ***	0.202 ***	0.363 ***	0.165 ***
	(0.042)	(0.043)	(0.051)	(0.043)
R&D		0.051 ***		
		(0.013)		
INFORM				0.121 ***
				(0.008)
CONTROL	Yes	Yes	Yes	Yes
_CONS	Yes	Yes	Yes	Yes
FIRM FIXED EFFECT	Yes	Yes	Yes	Yes
TIME FIXED EFFECT	Yes	Yes	Yes	Yes
N	15,085	15,085	15,085	15,085
R^2	0.877	0.561	0.456	0.569
F	184.824 ***	19.540 ***	58.582 ***	36.945 ***

Notes: Robust standard errors are in parentheses; *** indicate significant levels at 1%.

6.2. Moderating Effects: Internal and External Supervision

Corporate governance theory suggests that internal and external supervision helps to promote corporate innovation [106] and improve the corporate information environment [107]. To test whether supervision of firms helps strengthen the positive impact of IM on ESG performance, the following regression model was constructed.

$$ESG_{it} = \alpha_0 + \alpha_1 IM_{it} \times Moderating_{it} + \sum \alpha_i Control_{it} + \lambda_i + \delta_t + \varepsilon_{it} \quad (6)$$

$Moderating_{it}$ denotes different moderating variables, including INDIRECTOR, FUND, ANALYST, and REPORT. INDIRECTOR and FUND were used to measure the internal supervision, while ANALYST and REPORT were used to measure the external supervision.

From Table 8, we find that the regression coefficients of IM × INDIRECTOR, IM × FUND, IM × ANALYST and IM × REPORT are all significantly positive. This indicates that increasing the percentage of independent directors (INDIRECTOR), fund shareholding ratio (FUND), analyst focus (ANALYST) and reporting disclosure (REPORT) can strengthen the positive impact of IM on corporate ESG performance, which provides favorable empirical evidence for strengthening the internal and external supervision of manufacturing firms.

Table 8. Moderating effect of internal and external supervision.

Variable	(1) HESG	(2) HESG	(3) HESG	(4) HESG
IM × INDIRECTOR	0.552 ***			
	(0.113)			
IM × FUND		0.599 ***		
		(0.206)		
IM × ANALYST			0.076 ***	
			(0.018)	
IM × REPORT				0.062 ***
				(0.014)
CONTROL	Yes	Yes	Yes	Yes
_CONS	Yes	Yes	Yes	Yes
FIRM FIXED EFFECT	Yes	Yes	Yes	Yes
TIME FIXED EFFECT	Yes	Yes	Yes	Yes
N	15085	15085	15085	15085
R^2	0.561	0.560	0.560	0.560
F	19.724 ***	18.451 ***	19.297 ***	19.324 ***

Notes: Robust standard errors are in parentheses; *** indicate significant levels at 1%.

7. Conclusions

This study focuses on the impact of IM on corporate ESG performance using data from 2149 manufacturing listed firms in China from 2009–2021. The Ministry of Industry and Information Technology of China released a *List of intelligent manufacturing pilot demonstration projects* every year from 2015 to 2018. We used these lists to identify whether a firm implemented IM projects or not. Through this quasi-natural experiment, we examined whether firms that implemented IM projects had better ESG performance than firms that have not and further explored the channels through which IM impacts corporate ESG performance. This study clarifies that the implementation of IM projects is an important internal force for improving corporate ESG performance. The specific findings of the study are as follows.

Firstly, IM could significantly improve corporate ESG performance. This finding still held after a series of robustness tests. IM firms could form innovation networks with their holding firms through business interaction, technology transfer and achievement sharing [108]. Thus, IM not only improved the ESG performance of the firms themselves, but also had a positive impact on the ESG performance of their holding firms. Secondly, the

heterogeneity test based on corporate ownership shows that the impact of IM on improving ESG performance held only in non-state-owned firms. There was no significant impact of IM on ESG performance in state-owned firms. Compared to state-owned firms, non-state-owned firms face less social responsibility pressure, so there is more room for these firms to improve their ESG performance [97]. The heterogeneity test based on corporate location shows that IM significantly improved corporate ESG performance in eastern and western China but not in central and northeastern China. Central and northeastern China develop high-energy-consumption and high-pollution industries at the expense of environmental quality [98]. Local governments should enact stricter environmental regulations to promote sustainable development [101]. Thirdly, IM improved corporate ESG performance through two channels: innovation investment and information environment. IM promoted corporate innovation investment and improved the quality of the corporate information environment, both of which in turn improved corporate ESG performance. Increasing innovation investment enables firms to more accurately identify environmental, social and governance issues in production and make timely improvements [109]. As the quality of the corporate information environment improves, managers' opportunistic behavior will be more easily detected [73], which can help them improve their business behavior. Fourthly, this study also verifies that both internal and external supervision help strengthen the positive impact of IM on corporate ESG performance. This finding is similar to Yuan et al. [110]. A better regulatory environment helps to curb the unsustainable behavior of firms. Considering that some firms face dual goals of pursuing profits in the short term and improving ESG performance in the long term, these findings provide empirical evidence for strengthening the supervision of manufacturing firms.

8. Implications and Limitations

It can be seen that IM not only helps improve the production and operation efficiency of manufacturing firms [23–30], but also improves ESG performance, which in turn helps them gain a better business reputation [6], alleviate financing constraints [8] and increase market value [7]. Accordingly, this study makes the following implications.

Firstly, from the perspective of improving productivity, competitiveness and ESG performance, manufacturing firms should implement IM projects. Local governments should increase investment in new infrastructure construction such as 5G, artificial intelligence and Big Data technologies to strengthen the industrial foundation for manufacturing firms' implementation of IM projects. These new infrastructures can lower the threshold for manufacturing firms to implement IM projects. Governments could increase the number of 5G base stations to improve data transmission speed, build service platforms for artificial intelligence and Big Data technology applications, and increase research on industrial internet technologies, etc. Secondly, it is necessary to explore the barriers to the implementation of IM projects in non-state-owned firms and support them in political and financial areas. Non-state-owned firms have even less incentive to improve ESG performance, and their ESG performance is generally lower than that of state-owned firms. Promoting the implementation of IM projects in non-state-owned firms could more strongly improve the overall ESG performance of China's manufacturing industry. Thirdly, internal and external supervision should be strengthened to reinforce the positive impact of IM on corporate ESG performance. Independent directors and institutional shareholders are the two internal supervisors. Independent directors are able to perform the supervisor role well because they are able to make a more objective assessment of management performance [33]. Institutional shareholders have better access to corporate information, and their supervision is effective in order to ensure return on their investment [111]. Securities analysts are an external supervision force. More analyst teams focusing on listed firms and more reports disclosing listed firms can play a good supervision role. Fourthly, manufacturing firms should focus on innovation investment and information environment building and take advantage of AI technologies to fully unleash the potential of IM in improving their ESG performance.

This study theoretically reveals the internal force for manufacturing firms to improve ESG performance and clarifies two channels through which IM improves corporate ESG performance. It also provides practical guidance for manufacturing firms to improve productivity and ESG performance. However, some limitations still exist. Firstly, there are more than two channels through which IM affects corporate ESG performance. Future research could explore other important channels, such as human capital and executive compensation, etc. Secondly, this study only tests the heterogeneity of corporate ownership and corporate location. Future research could examine the heterogeneous effects of IM on ESG performance from a micro-perspective, such as entrepreneurship and corporate executive characteristics, etc. Thirdly, as this study treats corporate ESG performance as a whole, the impact mechanisms of IM on E, S and G could also be considered in the future.

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