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*Original Research*

# Effects of Intelligent Manufacturing on Environment, Social, and Governance (ESG) Performance: Evidence from China

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## Abstract

Intelligent manufacturing (IM) is a new technological paradigm, providing a brand-new idea for promoting sustainable development. Based on the IM pilot demonstration projects, this paper employs Chinese A-share manufacturing companies from 2012 to 2022 as a sample to investigate the impact of IM on corporate Environmental, Social, and Governance (ESG) performance. The results indicate that IM can significantly improve corporate ESG performance. Mechanism tests suggest that IM promotes corporate ESG performance by improving digital transformation and green innovation. Additionally, we find that the impact of IM has greatly boosted corporate ESG performance with the high level of urban resource endowment, industrial digitalization, internal governance, and external environmental regulation. The conclusions confirm the effect and internal logic of IM's influence on corporate sustainable development and provide valuable advice for relevant policies aimed at improving intelligence and sustainability.

**Keywords:** intelligent manufacturing, ESG performance, digital transformation, green innovation, sustainable development

## Introduction

Environmental issues like climate change, pollution, and resource depletion are increasingly widespread [1, 2], which have aroused great attention from governments and widespread concern from the public. The contradiction between economic growth and the natural environment has promoted investors and enterprises in the capital market to re-examine the traditional economic growth model. As an evaluation and measurement criterion for a company or organization's sustainable performance and non-financial risks, Environmental, Social, and Governance (ESG) performance is not only an extension and enrichment of the concept of socially responsible investment [3] but also an important indicator for evaluating the risks and potential of sustainable development [4]. With the global manufacturing industry moving towards advanced intelligence, digitalization, and greening, achieving sustainable development has become the consensus [5, 6]. China is the largest manufacturing country; its ESG processes are crucial for enhancing green development

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and achieving global sustainability goals. To respond to this practical need, promoting enterprise sustainability, particularly through ESG performance, has become a practical concern that needs to be solved [7].

Intelligent manufacturing (IM) is central to advancing digital, smart, and eco-friendly development in the manufacturing sector [8] and has led to profound changes in manufacturing production methods [9, 10]. China has formulated a series of development strategies with IM as the core content to seize development opportunities. In 2015, China's State Council issued the Made in China 2025 strategy. Following this, China's Ministry of Industry and Information Technology (MIIT) released the IM Development Plan (2016-2020) in 2016. Moreover, in 2021, the central government announced the Policy on Intelligent Transformation and Green Development of the Manufacturing Industry. These major strategic initiatives provide directional guidance for the development of IM and offer greater new opportunities for the implementation of ESG-related concepts in China.

However, in the new wave of global digital technology and intelligent development [11, 12], how to realize the effective integration of intelligent technology and manufacturing production is facing severe challenges. Besides, the growing market demand in the ESG field also imposes stricter requirements on enterprises for sustainable development [3, 13]. Under the dual pressures of intelligent technology and sustainable development, it is crucial to guide enterprises to change their development layouts and effectively improve their ESG performance with the help of IM. In light of this, this paper explores the influence of IM on corporate ESG performance, aiming to open the "black box" of the mechanisms by which intelligent technology affects the sustainability of micro-enterprises.

Under the tide of global intelligence, IM has become a significant paradigm in the field of technology [14], providing a specific way of thinking to solve the dilemma of sustainable development. IM is the new manufacturing mode based on advanced information technology and manufacturing technology, which can improve the design, production, management, and integration levels throughout the entire product life cycle by optimizing the manufacturing process [15]. To date, studies on the consequences of IM are relatively extensive. From the macro perspective, Zhang et al. [16] discovered that manufacturing intelligence favorably affects technological innovation, producing horizontal and vertical spillover effects. Li and Ling [17] found that IM enhances green development efficiency through technological innovation and energy utilization. From the micro perspective, some studies have also suggested that IM can not only improve operating efficiency [18], business performance [19], and competitive advantage [20] but also enhance labor productivity [21] and environmental innovation ability [22, 23]. As research has advanced, some studies have noted the impact of intelligent technologies on corporate sustainability. For example, Agarwal and Ojha [24] found that Industry 4.0 has led to advancements in manufacturing industries and systems that contribute to enhancing manufacturing sustainability. Ghobakhloo et al. [25] suggested that implementing intelligent automation can enhance firms' economic and environmental sustainability performance. However, these studies have not yet investigated the relationship between IM and firms' ESG performance. ESG is a key indicator that reflects the non-economic performance of enterprises and plays an increasingly prominent role in guiding sustainable development.

Existing studies have pointed out that governance factors and operational factors have an important impact on corporate ESG performance. The former mainly focuses on executive characteristics [26, 27] and shareholder behavior [28], while the latter includes corporate governance [29], digitalization [30], and mergers and acquisitions [31]. From the perspective of consequences, a large number of researchers pay attention to the impact of ESG performance on financial performance [32-34], enterprise value [35-37], innovation performance [38], etc. However, with the deepening of research, scholars gradually found that the goal of ESG conflicts with the traditional business goal of enterprises. Enterprises lack sufficient motivation to promote ESG performance, which often needs the traction and promotion of external policies, containing green finance [39], green credit [40, 41], low-carbon city pilot [42], environmental protection tax [43], and other policies on firms ESG. However, most existing studies focus on assessing ESG performance through environmental policies and related factors, rarely examining how new production paradigms affect corporate ESG performance in manufacturing.

Based on this, this paper seeks to systematically investigate how IM affects corporate ESG performance. This can assess how the new IM-based production paradigm affects micro-enterprises' sustainability and offer both theoretical and practical guidance for the government to develop effective strategies for long-term sustainable development. Specifically, based on IM pilot demonstration projects (IMPP), this paper employs the staggered difference-in-differences (TDID) method to empirically examine the link between IM and the sustainable ability of enterprises. The results show that IM has a positive impact on promoting corporate ESG performance, and the influencing mechanisms are digital transformation and green innovation. Further, this paper finds that in different cities' resource endowments, industrial digitalization levels, internal governance levels, and external environmental regulations, the influence of IM on corporate ESG performance is significantly different. The research conclusions provide essential evidence supporting IM's role in promoting the sustainable development of micro-enterprises.

Compared with the previous literature, the marginal contributions of this paper are reflected in the following three aspects: First, unlike past studies, this paper makes

a causal analysis of the current situation regarding the sustainable development of enterprises driven by emerging progressive technologies. Based on ESG performance, this paper investigates how IM affects the sustainability of enterprises, identifies conditions under which IM supports sustainable development, and contributes to the research on IM and corporate sustainability. Second, this paper opens the "black box" about how IM improves ESG performance and deepens the research on the indirect effect of IM on corporate sustainability. This paper overcomes the limitations of existing research on the indirect effects of IM on corporate ESG performance by exploring the specific influencing channels through digital transformation and green innovation. This method sheds light on how IM influences the black box of micro-enterprises. Third, from the perspectives of urban resource endowment, industrial digitalization level, internal governance, and external environmental regulation, this paper explores how IM influences the sustainability of enterprises under different conditions. It will help provide sufficient policy references for emerging economies to explore the effects of IM and enhance the level of intelligence while promoting green and sustainable development.

The paper is organized as follows: Section 2 covers theoretical analysis and hypotheses. Section 3 details the empirical models, variables, and data. Section 4 presents the empirical analysis and results. Section 5 offers conclusions and discussions.

## Theory Analysis and Research Hypotheses

### IM and ESG

As new intelligent technologies like cloud computing, blockchain, and artificial intelligence continue to emerge [44-46], enterprises seek to enhance IM to stay competitive in the market [47]. This process directly drives enterprises to enhance their ESG performance and sustainability [48].

First, intelligent technology applications enable enterprises to monitor and record pollutant emissions more accurately, which helps them adjust their production strategies in real-time, reduce carbon emissions [49], and enhance their green production capacity [22]. Moreover, IM can quickly pinpoint pollution sources during production and shift pollution control from "end-of" treatment to "source treatment". This progress will strengthen enterprises' green governance capabilities and improve their environmental performance [8, 50].

Second, IM can quickly capture and get the value demands of stakeholders such as management, employees, consumers, and the public through intelligent platforms [51]. Intelligent transformation has promoted enterprises to take relevant measures to fulfill their social responsibilities [52]. In addition, IM will, in turn, strengthen the supervision of stakeholders on enterprise production, urge enterprises to pay more attention to improving social responsibility, and force enterprises to improve their social responsibility performance [53].

Third, intelligent technology can be integrated with traditional technology. It helps to transform corporate management mode and boost governance capabilities [54]. On the one hand, IM can understand and meet the needs of internal employees in a timely manner through deep learning and big data algorithms, which helps to improve the human resources security system and optimize the internal governance environment of enterprises. On the other hand, with intelligent technology, enterprises can monitor and analyze risk assessment changes in real-time and develop optimal strategies accordingly [47], thereby improving the efficiency and effectiveness of risk assessment and enhancing the internal governance of enterprises.

Based on this, the research hypothesis is stated as follows:

H1: IM can positively promote firm ESG performance.

### IM, Digitalization, and ESG

Digital transformation is crucial for enhancing enterprise ESG performance [55, 56]. However, the manufacturing industry under the old production model has developed significant fixed capital investments and lacks sufficient funds to promote digital transformation. Moreover, digital transformation necessitates high-level talents with cutting-edge knowledge to provide technical support [57]. Unfortunately, traditional manufacturing processes often involve a large, low-skilled workforce, which hinders digital transformation. As a new paradigm driving technological change in manufacturing, IM could significantly boost the digital transformation of enterprises [14, 58]. In general, IM functions as a signal, which helps to strengthen the positive expectations of the capital market and attract more investment from stakeholders. This will help provide ample financial support for their digital transformation. Moreover, under the dual influences of the substitution effect and complementary effects [44, 59-61], IM will promote higher education agglomeration and optimize the labor structure within enterprises, thereby providing greater talent support for digital technological development. High-level human capital facilitates the integration of digital and traditional technologies, aiding digital transformation.

So, the research hypothesis is proposed as follows.

H2: IM can promote corporate ESG performance by enhancing digital transformation.

### IM, Green Innovation, and ESG

Green innovation serves as a significant pathway for enterprises to progress towards green development [62]. However, faced with the dual externalities of green innovation [63], enterprises often lack sufficient

motivation to carry out green innovation activities. Overtly, IM can promote green innovation.

First, IM can strengthen big data mining capabilities, thereby boosting the green innovation potential of enterprises [64]. It assists enterprises in integrating heterogeneous and non-standardized data to support green production and management [65] and also enables them to quickly identify users' green preferences and increase their willingness to adopt green innovation. Second, IM can enhance information transparency within the enterprise, thereby fostering green innovation [66]. IM modifies the internal management framework of enterprises [67] and reduces the risks associated with green innovation. This can lower communication costs and enhance the efficiency of green innovation within enterprises. Moreover, IM connects enterprises closely with external innovation partners, enabling the sharing and spreading of knowledge and technology [68]. This can break the barriers to entry for environmental protection technology, increase the knowledge base for green innovation [69], and help boost the vitality of green innovation.

Hence, the research hypothesis is proposed as follows.

H3: IM can promote corporate ESG performance by improving green innovation.

## Research Design

### Empirical Design

We utilize Model (1) to investigate the influence of IM on firm ESG performance.

$$ESG_{ijt}=\beta_0+\beta_1 IM_{it}+\beta_2 X_{it}+\beta_3 Z_{jt}+\theta_i+\delta_t+\varepsilon_{ijt} \quad (1)$$

*i*, *j*, and *t* denote firm, region, and year, respectively. $IM_{it}$ equals 1 if enterprise *i* in region j has implemented IMPP in year t; otherwise, it is 0. $X_{it}$ represents the set of firm characteristics that has been proved to affect corporate ESG performance. $Z_{jt}$ represents the set of region characteristics that has been proved to affect corporate ESG performance. $\theta_i$ and $\delta_t$ denote the firm and the year fixed effect, respectively. $\varepsilon_{ijt}$ is the random error term.

### Variables Description

#### *ESG Performance*

In this study, we use the Huazheng ESG rating score to measure corporate ESG performance. ESG ratings are categorized into nine grades, from lowest to highest: C, CC, CCC, B, BB, BBB, A, AA, and AAA, and are assigned a value of 1 to 9 in that order. The higher the score is, the better the ESG performance of the enterprise.

Compared with other ESG indices, the Huazheng ESG index has the following advantages: First, in terms of indicator construction, the Huazheng ESG index draws upon the development experience of international mainstream ESG systems and is adjusted based on the characteristics of Chinese listed companies [70]. The index is authoritative and reliable. Second, regarding indicator content, the Huazheng ESG index encompasses three primary dimensions (E for Environment, S for Society, and G for Corporate Governance) and 16 secondary indicators, which include variables such as environmental management systems, social responsibility reports, and the quality of information disclosure. These variables are crucial in reflecting the sustainable development capabilities of enterprises [71]. Third, in terms of data updating, the Huazheng ESG index employs a combination of quarterly evaluations and dynamic tracking to collect and organize data. This indicator system is both rapid and up-to-date, enabling a timely reflection of corporate ESG performance.

#### *IM*

According to related research [8, 72], we take IMPP as a quasi-natural experiment and utilize the TDID method to examine the impact of IM on corporate ESG performance. As a key response to the national IM development strategy, the IMPP used a pilot-first approach before broader implementation. The selection of pilot enterprises entails various processes, including screening and recommendation by local governments, approval by relevant departments, expert review, and final determination and release. From 2015 to 2018, MIIT selected 305 enterprises to implement the IMPP. The breakdown of enterprises implementing the IMPP by year is as follows: 46 in 2015, 63 in 2016, 97 in 2017, and 99 in 2018. This paper identifies these enterprises based on MIIT's published list, matches and verifies the piloted enterprises, and ultimately compiles the list of enterprises implementing IM.

#### *Control Variables*

To reduce the interference of other factors on the study's conclusions, we controlled for individual and regional variables that may affect corporate ESG performance. According to Cheng et al. (2024) [73], the individual variables include company size, company age, and other relevant factors; the regional variables encompass gross domestic product and local fiscal budget expenditure, among others. These control variables are essential for our analysis. They are selected to better eliminate the influence of other factors that may interfere with the empirical results, thereby ensuring the reliability of the research findings [74]. For example, gross domestic product and expenditure in local fiscal budgets can provide firms with increased environmental opportunities and economic incentives [75], which may

Table 1. Definitions of the variables.

| Variables | Name | Definition |
|---|---|---|
| ESG | ESG score | Huazheng ESG score |
| IM | Intelligent manufacturing | If a company implements IMPP, the virtual variable is 1, otherwise, it is 0 |
| SIZE | Company scale | The logarithm value of the total assets of a company |
| AGE | Company age | The logarithm of the number of years since the establishment of a company |
| BTM | Book-to-market ratio | The ratio of shareholders' equity to market capitalization |
| MFR | Management fee rate | The ratio of management expenses to operating income |
| TEC3 | Total compensation of the top three executives | The logarithm of the top three executives' compensation |
| DUAL | Consolidation of two positions | If the chairman and CEO are the same person, the dummy variable is 1, otherwise, it is 0 |
| FLR | Financial leverage ratio | The ratio of debt capital to total assets |
| GO | Growth opportunity | The logarithm of Tobin's Q value |
| BS | Board size | The logarithm of the number of directors |
| NPR | Nature of the property right | If a company is a state-owned enterprise, the dummy variable is 1, otherwise, it is 0 |
| GDP | Gross domestic product | The logarithm of urban GDP |
| PSP | Proportion of secondary production | The ratio of secondary industry to GDP |
| ML | Marketization level | The logarithm of the marketization index |
| EFB | Expenditure in local fiscal budget | The logarithm of expenditure in urban financial budgets |

Table 2. Descriptions of the variables.

| VarName | Obs | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| ESG | 13560 | 71.564 | 10.663 | 0 | 90.930 |
| IM | 13560 | 0.028 | 0.165 | 0 | 1 |
| SIZE | 13560 | 22.100 | 1.170 | 19.774 | 26.135 |
| AGE | 13560 | 2.061 | 0.754 | 0.693 | 3.332 |
| BTM | 13560 | 0.327 | 0.154 | 0.004 | 0.789 |
| MFR | 13560 | 0.087 | 0.068 | 0.007 | 0.849 |
| TEC3 | 13560 | 14.480 | 0.721 | 9.385 | 16.540 |
| DUAL | 13560 | 0.291 | 0.454 | 0 | 1 |
| FLR | 13560 | 0.410 | 0.191 | 0.065 | 0.902 |
| GO | 13560 | 0.648 | 0.485 | -0.167 | 2.133 |
| BS | 13560 | 2.123 | 0.194 | 1.609 | 2.708 |
| NPR | 13560 | 0.334 | 0.472 | 0 | 1 |
| GDP | 13560 | 8.708 | 0.981 | 5.033 | 9.729 |
| PSP | 13560 | 42.350 | 11.142 | 15.200 | 76.950 |
| ML | 13560 | 2.242 | 0.211 | 0.117 | 2.457 |
| EFB | 13560 | 15.820 | 0.812 | 11.711 | 16.653 |

affect firms' ESG performance. The definitions of the main variables are shown in Table 1.

*Data Resources*

This study uses data from listed companies in the Chinese A-share manufacturing sector from 2012 to 2022 as the research sample. To ensure the reliability of data, our study excludes firms in the financial and insurance industries, as well as those companies designated as "ST", "*ST", "suspension of listing", or "termination of listing". Besides, all continuous variables were winsorized at the 1% level of each tail. We finally obtained 13560 valid samples. Data for this paper were sourced from Wind and CSMAR databases and company annual reports. Descriptive statistics of these variables are provided in Table 2.

## Empirical Analysis

### Baseline Results

Table 3 presents the basic regression findings. Column (1) presents the direct regression results between IM and ESG performance, revealing that the coefficient of IM on corporate ESG performance is significantly positive. Column (2) displays the regression results after including several control variables, showing that the coefficient of IM remains positive at the 1% significance level. The results manifest that IM can significantly boost corporate ESG performance in manufacturing. These findings support H1.

From the control variables, the coefficients of SIZE and GO are significantly positive, indicating that improving enterprises' scale and growth opportunities can somewhat promote ESG performance. This finding is consistent with the conclusions of Agarwala et al. (2023) [76], which indicate that a firm's ESG performance increases with firm size within a certain range. The coefficients of AGE, MFR, FLR, BS, and PSP are significantly negative, suggesting that the increasing agency costs and age of firms may lead managers to adopt conservative growth strategies, which could hinder the firms' ESG performance [77]. The estimated coefficients of BTM, TEC3, DUAL, NPR, GDP, ML, and EFB are not significant, which may be attributed to these variables playing a lesser role in influencing the ESG performance of the firms.

### Robustness Test

The above analysis confirmed that IM can promote corporate ESG performance. However, some issues of potential endogeneity remain. To ensure the reliability of our findings, we conducted several robustness checks from the following perspectives:

*Parallel Trend Test*

Generally speaking, if corporate ESG performance is affected by unpredictable factors, enterprises implementing IMPP will not exhibit time-based differences in their ESG performance. Moreover, if low ESG performance itself drives the implementation of IMPP, then before IMPP is implemented, the ESG performance of some enterprises would differ from those that have not implemented IMPP. Based on this, this study employs the parallel trend test to examine the dynamic effect of IM on firm ESG performance. Fig. 1 displays the results. It demonstrates that before IMPP implementation, there was no notable difference in ESG performance trends between companies affected by IMPP and those unaffected. However, after the IMPP was implemented, the impact of ESG performance on affected companies improved significantly. These results provide further support for our findings.

*Placebo Test*

The impact of IM on a firm's ESG performance might be affected by unobservable factors, which could result in estimation errors. We use a placebo test to determine whether the improvement of corporate ESG performance is aroused by other random factors [78]. First, we randomly generated experimental groups based on IMPP's distribution in the benchmark regression. We then randomly sampled 500 times to construct a "pseudo-policy dummy variable". Finally, we use model (1) again. Fig. 2 reveals that the effect of IM on corporate ESG performance isn't affected by other random factors. These findings bolster the credibility of our estimation results, indicating their high reliability.

*PSM-DID*

In this part, this paper employs the propensity score matching method (PSM) to rematch the control group samples and re-examines the nexus of IM between corporate ESG performance. First, we choose control variables for the benchmark regression as covariates and apply kernel matching, nearest neighbor matching, and radius matching to address systematic differences between the experimental and control groups. Subsequently, this paper reevaluates the matched observations. Table 4 shows the results, which indicates the robustness of the core conclusions of this paper.

*Excluding Other Policy Interference*

In estimating the nexus between IM and corporate ESG performance, other policies at similar times will inevitably lead to an overestimation of the influence of IM. To alleviate the interference of other policies on the basic conclusion, this paper incorporates two policy variables into the benchmark regression model.

Table 3. Baseline results.

| Variables | (1) | (2) |
|---|---|---|
| | ESG | ESG |
| IM | 1.806*** | 1.440*** |
| | (0.418) | (0.406) |
| SIZE | / | 1.583*** |
| | / | (0.175) |
| AGE | / | -1.070*** |
| | / | (0.261) |
| BTM | / | 1.453 |
| | / | (1.074) |
| MFR | / | -2.892*** |
| | / | (1.076) |
| TEC3 | / | 0.116 |
| | / | (0.151) |
| DUAL | / | -0.202 |
| | / | (0.181) |
| FLR | / | -3.811*** |
| | / | (0.799) |
| GO | / | 0.679** |
| | / | (0.337) |
| BS | / | -0.806* |
| | / | (0.488) |
| NPR | / | 0.166 |
| | / | (0.413) |
| GDP | / | 0.232 |
| | / | (0.538) |
| PSP | / | -0.034* |
| | / | (0.020) |
| ML | / | 0.539 |
| | / | (1.056) |
| EFB | / | -0.781 |
| | / | (0.498) |
| Firm Fixed | YES | YES |
| Year Fixed | YES | YES |
| Adj-R2 | 0.884 | 0.888 |
| N | 13396 | 13396 |

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses are robust standard errors clustered at the firm-year level. (hereinafter inclusive).

(1) Environmental Protection Tax (EPT)[1]. We add a dummy variable for EPT to the model (1). Column (1) of Table 5 shows the regression results. (2) Low-Carbon City Pilot Policy (LCCP)[2]. To eliminate the interference of LCCP, we included a dummy variable for LCCP in Model (1), shown in Column (2) of Table 5. The results indicate that the coefficient of IM remains significantly positive, though its size has decreased. Moreover, we also consider the joint influence of EPT and LCCP, and the results are displayed in Column (3) of Table 5. It indicates that after accounting for EPT and LCCP on the ESG performance, the coefficient of IM remains significantly positive at the 1% level, confirming the reliability of our findings.

*Other Robustness Tests*

To verify the conclusion's reliability, this study also selects alternative variables, changes the sample range, and employs other methods for robustness tests.

i. Replace the explained variable. We have chosen the Bloomberg ESG scores to measure corporate ESG performance. The results are displayed in Column (1) of Table 6, indicating that changing the ESG scoring method does not notably affect our conclusions. ii. Change the sample range. We change the sample interval from the following two aspects. First, the COVID-19 pandemic has had a lasting and significant effect on global business operations. Second, in 2013, China entered the big data era, and the explosion of information has transformed the business landscape and may influence business activities. Based on this, we excluded 2020, retaining 2010 to 2018, and retaining 2013 to 2022 for regression analysis again. Columns (2), (3), and (4) of Table 6 show the results, respectively. iii. Eliminate municipalities directly under the central government. To alleviate the interference of urban administrative structure on the research findings, this paper excludes samples from the four central municipalities—Beijing, Shanghai, Tianjin, and Chongqing—and performs the regression analysis again. The results are displayed in Column (5) of Table 6. iv. Account for the fixed effects of industries and regions. The characteristics of industries and provinces may affect the research conclusions; this paper additionally incorporates the fixed effects of industry and region in Column (6) of Table 6. v. Control other variables. According to existing research,

[1] EPT is an important market-oriented environmental law; it can not only help curb corporate illegal activities but also reduce carbon emissions and promote the green transformation of enterprises [79]. To accurately identify the effect of IM on corporate ESG performance, it is necessary to eliminate the policy interference of EPT.

[2] LCCP is a crucial policy to enhance low-carbon industries and lifestyles. As a comprehensive regulation and policy for the government's low-carbon supervision, LCCP plays a crucial role in promoting sustainable development [80].

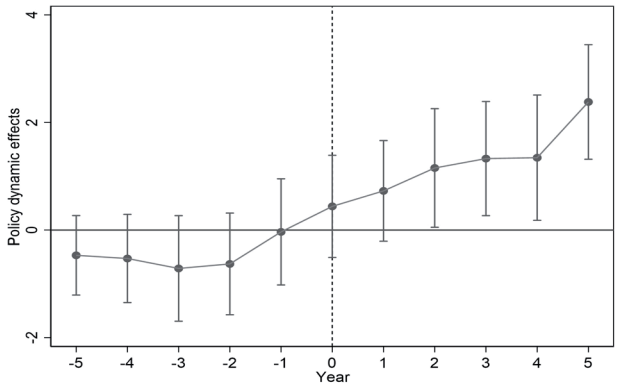


Fig. 1. Parallel trend test.

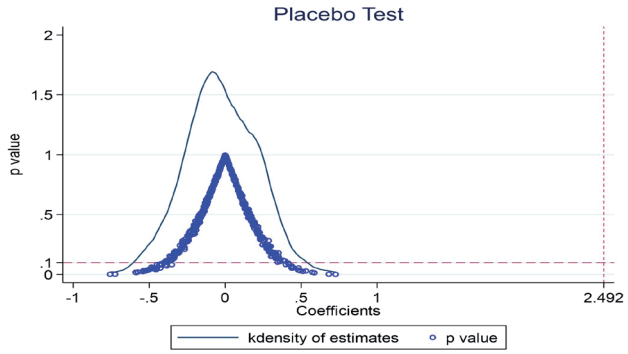


Fig. 2. Placebo test.

stakeholders' shareholding will also affect enterprises' ESG performance [28, 81]. Hence, we also incorporate the proportion of female executives (PFE) and the shareholding of institutional investors (SII). Column (7) of Table 6 displays the results. To sum up, the above analysis results are consistent with our initial findings.

## Mechanism Analysis

The above research results demonstrate that IM significantly enhances the sustainable ability of enterprises. This paper further investigates the mechanisms by which IM promotes corporate ESG performance, and the mechanism model is:

$$M_{ijt}=\gamma_0+\gamma_1 IM_{it}+\gamma_2 X_{it}+\gamma_3 Z_{jt}+\theta_i+\delta_t+\varepsilon_{ijt} \quad (2)$$

$M$ is the mechanism variables, including digital transformation and green innovation. The explanations of the other variables are the same as those of model (1).

The first mechanism that this paper focuses on is digital transformation. Utilizing text analysis, this paper analyzed the frequency of "digital transformation" words in corporate annual reports to derive a digital transformation index. First, digital transformation keywords are categorized into "application of underlying technology" and "application of digital technology". Then, we organize these keywords and use the proportion of their frequency relative to the total word count in the text as an index to measure digital transformation[3]. Given the numerous zero values in the digital word frequency, this paper adds 1 to the indicators and then takes the logarithm. Column (1) of Table 7 shows the mechanism results of digital transformation; the coefficient of IM is positive and significant at 1%, suggesting that IM can significantly advance digital transformation. The results claim that IM can enhance corporate ESG performance by driving digital transformation, thereby verifying H2.

The second mechanism that this paper focuses on is green innovation. Considering that green patents not only have environmental protection characteristics but also reflect the innovation advantages of enterprises, this paper identifies green patents based on IPC codes in the List of Green Patents issued by the World Intellectual Property Organization. The total number of applications for green invention and green utility model patents is

[3] The "application of underlying technology" covers four aspects: artificial intelligence, cloud computing, big data, and blockchain, with 90 keywords. The "application of digital technology" involves 46 keywords such as networking, internet plus, and mobile Internet. We analyze the keywords in these dimensions and use their frequency proportion relative to the total word count in the text to gauge corporate digital transformation.

Table 4. PSM-DID.

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| | Kernel matching | Nearest neighbor matching | Radius matching |
| IM | 1.369*** | 1.376*** | 1.478*** |
| | (0.401) | (0.422) | (0.519) |
| Controls | YES | YES | YES |
| Firm Fixed | YES | YES | YES |
| Year Fixed | YES | YES | YES |
| Adj-R2 | 0.551 | 0.570 | 0.540 |
| N | 12486 | 7776 | 5055 |

Table 5. Excluding other policy interference.

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| IM | 1.412*** | 1.439*** | 1.412*** |
| | (0.407) | (0.406) | (0.407) |
| EPT | 0.332 | / | 0.329 |
| | (0.252) | / | (0.253) |
| LCCP | / | 0.071 | 0.017 |
| | / | (0.223) | (0.222) |
| Controls | YES | YES | YES |
| Firm Fixed | YES | YES | YES |
| Year Fixed | YES | YES | YES |
| Adj-$R^2$ | 0.888 | 0.888 | 0.888 |
| N | 13396 | 13396 | 13396 |

regarded as an index to measure green innovation. Due to many zero values in the patent applications, this paper adds 1 to all patent counts and then takes the logarithm.

Column (2) of Table 7 shows the mechanism results of green innovation; the estimation coefficient of IM is positive and significant, confirming that IM has notably advanced green innovation. The results show that IM can facilitate corporate ESG performance by improving green innovation, thereby verifying H3.

## Heterogeneity Analysis

The above analysis is primarily based on an overall level of discussion. The characteristics of the industry in which an enterprise operates and the different external environments may affect the role of IM. This paper further adopts the cross-sectional grouping method to examine the heterogeneous influence of IM on corporate ESG performance, aiming to provide more detailed empirical evidence for the research content of this paper.

### *Regional Resource Endowment*

IM has significantly contributed to the sustainable development of enterprises, but its impact may vary depending on regional resource endowments [82]. Based on this, referring to the National Sustainable Development Plan for Resource-based Cities (2013-2020), this paper divides the total sample into two groups: resource-based areas (RBA) and non-resource-based areas (NRBA) and performs a comparative analysis. The results are presented in Columns (1) and (2) of Table 8. In Column (1), IM has a significant positive impact on corporate ESG performance in high-resource regions. IM also positively affects ESG performance in low-resource regions, but this effect is not statistically significant in Column (2). These results suggest that IM more strongly supports the sustainable development of enterprises in regions with abundant resources. These findings indicate that varying regional resource endowments result in imbalances in the effects of IM on corporate sustainable ability. IM is more

Table 6. Other robustness tests.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | Bloomberg ESG Scores | Excluding 2020 | 2010-2018 | 2013-2022 | Excluding the major cities | Controlling industry and regions | Controlling other variables |
| IM | 1.678** | 1.381*** | 1.472*** | 1.481*** | 1.559*** | 1.353*** | 1.400*** |
| | (0.707) | (0.382) | (0.384) | (0.448) | (0.434) | (0.412) | (0.405) |
| PFE | / | / | / | / | / | / | -0.560 |
| | / | / | / | / | / | / | (0.748) |
| SII | / | / | / | / | / | / | -0.007 |
| | / | / | / | / | / | / | (0.005) |
| Controls | YES | YES | YES | YES | YES | YES | YES |
| Firm Fixed | YES | YES | YES | YES | YES | YES | YES |
| Year Fixed | YES | YES | YES | YES | YES | YES | YES |
| Adj-$R^2$ | 0.827 | 0.899 | 0.909 | 0.871 | 0.888 | 0.889 | 0.888 |
| N | 4557 | 11661 | 10419 | 11033 | 11082 | 13396 | 13364 |

influential in promoting the sustainable development of enterprises in regions with abundant resources.

*Digitalization Degree of Industry*

China's digital economy has reached a stage of extensive development [83], but there are significant differences in digital infrastructure and digital resource integration capabilities among different industries [84]. The impact of IM on promoting enterprise sustainability may differ across industries with varying levels of digitalization. In this context, based on the median digital level of industry, this paper divides the overall sample into two groups, higher digital levels (HDL) and lower digital levels (LDL), and performs a comparative analysis. The results are displayed in Columns (3) and (4) of Table 8. The findings show that IM significantly improves corporate ESG performance in highly digitized industries but has little impact on those in less digitized sectors. This may be because a strong digital foundation enhances enterprises' ability to acquire external resources, facilitating the acceleration of digital transformation, thereby providing power for the sustainable development of enterprises.

*Internal Governance*

Perfect internal governance is an important guarantee for reducing potential risks and enhancing the competitiveness of enterprises [85, 86]. Promoting IM for sustainable development may be more impactful in companies with stronger internal governance. To confirm this hypothesis, this paper selects the Dibo internal control index as the proxy index for corporate internal governance[4] and divides the sample into two groups based on the median: high internal governance (HIG) and low internal governance (LIG). It then conducts a grouped regression. Columns (5) and (6) of Table 8 show that IM more effectively enhances corporate ESG performance in HIG compared to LIG. These findings suggest that improving ESG performance depends on the level of internal governance, with lower internal governance levels limiting IM's effectiveness in boosting the sustainable ability of enterprises.

Table 7. Mechanism analysis.

| Variables | (1) | (2) |
|---|---|---|
| | Digital transformation | Green innovation |
| IM | 0.267*** | 0.128** |
| | (0.074) | (0.064) |
| Controls | YES | YES |
| Firm Fixed | YES | YES |
| Year Fixed | YES | YES |
| Adj-$R^2$ | 0.720 | 0.730 |
| N | 13396 | 13392 |

[4] The Dibo internal control index consists of five specific dimensions: the strategic level index, the operational level index, the reporting reliability index, the legal compliance index, and the asset security index.

Table 8. Heterogeneity analysis.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | RBA | NRBA | HDL | LDL | HIG | LIG | HER | LER |
| IM | 1.493*** | 1.194 | 1.303** | 0.644 | 1.315*** | 1.193 | 1.956*** | 0.719 |
| | (0.442) | (1.110) | (0.651) | (0.625) | (0.453) | (0.731) | (0.540) | (0.560) |
| Controls | YES | YES | YES | YES | YES | YES | YES | YES |
| Firm Fixed | YES | YES | YES | YES | YES | YES | YES | YES |
| Year Fixed | YES | YES | YES | YES | YES | YES | YES | YES |
| Adj-$R^2$ | 0.888 | 0.889 | 0.877 | 0.896 | 0.869 | 0.899 | 0.891 | 0.892 |
| N | 11848 | 1543 | 3673 | 9329 | 6409 | 6403 | 7373 | 5360 |

*External Environmental Regulation*

Strict environmental regulations may lessen pollution by businesses and offer crucial support for IM to foster sustainable development [87, 88]. IM's role in advancing the sustainability of enterprises is more pronounced in areas with strong environmental regulations. According to the measure of environmental regulation[5], this paper separates the samples into two groups based on the median value: high environmental regulation (HER) and low environmental regulation (LER) for regression analysis. A higher index indicates stricter environmental regulations in the area. Columns (7) and (8) of Table 8 show that IM has a greater impact on enhancing ESG performance when enterprises encounter significant external environmental pressure. These findings indicate that stringent external environmental regulations can support IM in boosting corporate ESG performance.

## Conclusions

Environmental, social, and governance are the three core pillars of sustainable development and are essential for achieving sustainability goals. As a key element of the new industrial revolution, IM underpins enterprises' efforts to advance sustainable development. This paper finds that IM promotes firm ESG performance, facilitating their sustainable ability. Moreover, digital transformation and green innovation are important channels for IM to advance corporate ESG performance. Furthermore, this paper also finds that the relationship between IM and corporate ESG performance is more pronounced when high regional resource endowment, high industry digitization, a higher level of internal governance, and stricter external environmental regulation are present.

By reviewing the above conclusions, the following policy implications can be drawn.

First, enterprises should attach importance to IM and actively promote intelligent transformation. With the fast advancement of intelligent technology, the value creation effect of IM on enterprises is not only reflected in economic performance but also significantly promotes non-economic performance in areas such as ESG performance. Therefore, for emerging manufacturing powers, it is necessary to seize the wave of intelligent transformation in time and actively promote IM. Enterprises should be encouraged to purposefully and systematically deploy and implement digital transformation strategies and to take on more environmental, social, and corporate governance responsibilities through IM, thus promoting sustainable ability.

Second, businesses should prioritize digital transformation and green innovation and further dredge the channels for IM to promote the sustainability of enterprises. On the one hand, government departments should continually enhance the digital technology support system and upgrade the regional digital infrastructure construction through government subsidies, system guarantees, and other measures, thereby stimulating the digital transformation potential of enterprises. On the other hand, enterprises should actively utilize intelligent platforms and other equipment to strengthen resource integration and information sharing with external subjects, improve their green innovation capabilities, and thus provide sufficient intrinsic motivation for enhancing their ESG performance.

Third, the government should strengthen environmental regulations and promote IM to form a joint force for corporate ESG performance. In the future, the government should intensify the enforcement of environmental regulations, establish a standardized monitoring and law enforcement system, and impose

[5] Five indicators are used to create a comprehensive environmental regulation index: industrial smoke (dust) removal rate, industrial sulfur dioxide removal rate, domestic waste harmless treatment rate, centralized sewage treatment rate, and general industrial solid waste utilization rate. The process involves standardizing each indicator, determining weights using the entropy method, and then calculating the comprehensive index based on these weights and standardized values.

penalties for illegal activities. By implementing stricter environmental regulations, regions can provide robust institutional support for IM and unlock the full potential of sustainable ability. Moreover, enterprises should also establish a series of measures to optimize internal supervision capabilities and improve internal governance, thereby better supporting their sustainable capabilities.

Research limitations and future directions: (1) This study has explored the various impact channels and economic effects of IM but has not extensively covered spillovers. Future research could address this by using spatial DID models to examine the spillover effects of pilot firms. Additionally, future studies could investigate IM's impact on regional sustainable development, such as water conservation, ecological restoration, and social equity. (2) Although this paper focuses on IMPP to explore the nexus between IM and corporate ESG performance, the policy may not accurately reflect the level of enterprise-intelligent transformations. In the future, we will need more granular and dynamic data on IM to better reflect and capture the temporal and spatial variations in this field.

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## Conflict of Interest

The authors declare no conflict of interest.

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