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CHEN XU

RESEARCH ON THE IMPACT OF INTELLIGENT MANUFACTURING ON ENTERPRISE ESG PERFORMANCE

Index

041301

Business Administration

Doctoral Dissertation

Supervisor

Batkhuyag Ganbaatar, Ph.D/Professor

Ulaanbaatar. 2026

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A single-subject dissertation for the degree of Doctor of Philosophy (Ph.D) in Business Administration was presented on May 21th, 2026, in Room 102, Building C of the University of Finance and Economics.

Doctoral student..Chen Xu

STATEMENT

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIXES

LIST OF ABBREVIATIONS

ESG	Enterprise ESG Performance
IM	Intelligent Manufacturing
ROA	Return on Total Assets
SOE	State-owned Enterprise
GTI	Green Technological Innovation
RBV	Resource Based View
VRIN	Valuable, Rare, Inimitable, Non-substitutable
VRIO	Valuable, Rare, Inimitable, Organized
CPS	Cyber Physical Systems
IoT	Internet of Things
NLP	Natural Language Processing
DJSI	Dow Jones Sustainability Index
MSCI	Morgan Stanley Capital International
FTSE Russell	Financial Times Stock Exchange Russell
WIPO	World Intellectual Property Organization
IPC	International Patent Classification
CSMAR	China Stock Market & Accounting Research Database
WIND	Wind Information Database
RESSET	ResSet Database
PSFA	Panel Stochastic Frontier Approach
DID	Difference-in-Differences
PSM	Propensity Score Matching
GMM	Generalized Method of Moments

AR	Autoregressive Test
BSE	Beijing Stock Exchange
SASAC	State-owned Assets Supervision and Administration Commission of the State Council
AMAC	Asset Management Association of China
CSRC	China Securities Regulatory Commission
UNEP	United Nations Environment Programme
UN PRI	United Nations Principles for Responsible Investment
CBAM	Carbon Border Adjustment Mechanism
SDGs	Sustainable Development Goals

TERMONOLOGY DEFINITION

Environmental, Social, and Governance

A framework for evaluating corporate sustainability, non-financial performance, and long-term development quality, covering three core dimensions: Environmental (focusing on enterprises' impacts on natural ecosystems, e.g., carbon emission reduction, energy efficiency improvement), Social (concerning interactions with stakeholders such as employees, customers, and communities), and Governance (relating to internal governance structures like board independence and information disclosure transparency).

Intelligent Manufacturing

A firm-level mode of manufacturing transformation characterized by the deep integration of advanced manufacturing technologies with new-generation digital and information technologies across the full production life-cycle, including design, production, management, logistics, and service. In this dissertation, intelligent manufacturing is not understood as the mere adoption of automated equipment or isolated digital tools. Rather, it refers to a broader organizational and technological system in which data connectivity, intelligent equipment, real-time monitoring, algorithmic optimization, and cross-functional coordination are combined to enhance firms' capabilities for self-perception, self-learning, self-decision-making, self-execution, and self-adaptation. This broader definition emphasizes that intelligent manufacturing is simultaneously a technological upgrade, a production reorganization process, and a capability-building mechanism with implications extending beyond operational efficiency to corporate sustainability and governance outcomes.

Return on Total Assets

Net income divided by total assets, reflecting enterprises' internal cash-generating capacity and profitability, which directly affects their ability to invest in ESG related activities.

State-owned Enterprise

Enterprises where the state holds a controlling stake, often facing stronger policy pressure and social responsibility requirements, and playing an important role in national industrial strategy and green transition.

Green Technological Innovation

Innovation activities aimed at environmental protection, energy efficiency improvement, and emission reduction, identified based on the International Patent Classification (IPC) green technology list issued by the World Intellectual Property Organization (WIPO), including green product innovation and green process innovation.

Resource Based View

A theoretical perspective that argues enterprises achieve competitive advantage through the possession and effective utilization of heterogeneous and imperfectly mobile resources (tangible and intangible).

Valuable, Rare, Inimitable, Non-substitutable

A framework proposed by Barney (1991) for evaluating enterprise resources, suggesting that only resources with these four characteristics can help enterprises gain and sustain competitive advantage in market competition.

Valuable, Rare, Inimitable, Organized

A refined framework of VRIN proposed by Rothaermel (2013), emphasizing not only the intrinsic characteristics of resources but also enterprises' organizational capabilities to effectively capture value from these resources, further supplementing the Resource Based View.

Cyber Physical Systems

Integrated systems of computational and physical processes, a core technology supporting Industry 4.0 and intelligent manufacturing, enabling deep integration of digital technologies and physical production processes.

Internet of Things

A network of physical devices embedded with sensors, software, and connectivity to exchange data, enabling real-time monitoring, data collection, and coordination across production links in intelligent manufacturing.

Natural Language Processing

A branch of artificial intelligence used in the Huazheng ESG rating system to enhance the accuracy and objectivity of ESG assessment through semantic analysis of corporate disclosures and unstructured data.

Dow Jones Sustainability Index

One of the earliest ESG based indices (launched in 1999), evaluating enterprises' comprehensive sustainability performance across corporate governance, risk management, brand management, climate change mitigation, supply chain standards, and labor practices, with industry-specific weighting schemes to enhance cross-sector comparability.

Morgan Stanley Capital International

A global ESG rating agency whose ESG ratings focus on the three core pillars (Environmental, Social, Governance) and incorporate core indicators covering environmental protection, labor relations, board structure, and corporate ethics. It emphasizes enterprises' exposure to ESG risks and risk management capabilities relative to industry peers, widely used in global investment decision-making.

Financial Times Stock Exchange Russell

An international ESG rating agency that provides systematic evaluation of enterprises' sustainable development performance, serving as an important reference for global investors in ESG oriented investment decisions.

World Intellectual Property Organization

An intergovernmental organization that issues the International Patent Classification green technology list, providing a standard for identifying green patents and serving as the basis for measuring green technological innovation in the study.

International Patent Classification

A global classification system for patents, used in the study to identify green technological innovation based on WIPO's green technology list, ensuring the accuracy of GTI measurement.

China Stock Market & Accounting Research Database

An authoritative database providing enterprise-level financial data, corporate governance data, patent data, and digital transformation data for Chinese listed companies.

Wind Information Database

A comprehensive financial database providing ESG ratings (including Huazheng ESG ratings), financial indicators, and corporate disclosure data for Chinese listed companies.

ResSet Database

A professional database offering financial and corporate governance data for Chinese listed companies, used to supplement and verify data from CSMAR and WIND, ensuring data reliability.

Panel Stochastic Frontier Approach

An econometric method used in the study to construct the enterprise-level Intelligent Manufacturing Index (IM). It estimates technological efficiency in transforming intelligent manufacturing inputs (capital and labor) into economic outputs (operating revenue), generating a continuous index reflecting enterprises' intelligent manufacturing levels.

Difference-in-Differences

A quasi-natural experimental method used to identify causal effects. By comparing the changes in outcomes between a treatment group and a control group before and after an intervention, it mitigates endogeneity concerns.

Propensity Score Matching

A statistical method used to mitigate selection bias. It estimates propensity scores of enterprises adopting intelligent manufacturing through a logit model (based on firm characteristics such as size and profitability), then matches treated and control units to construct a comparable sample for subsequent causal inference.

Generalized Method of Moments

An econometric method used to address endogeneity concerns in dynamic panel data models. The study adopts the System GMM approach to mitigate bias from lagged dependent variables and reverse causality.

Autoregressive Test

A diagnostic test for serial correlation in regression residuals, including AR(1) and AR(2) tests. In the System GMM framework, it verifies whether there is second-order serial correlation in first-differenced errors, a key condition for valid GMM estimates.

Beijing Stock Exchange

A stock exchange in China established to serve innovative small and medium-sized enterprises, with distinct regulatory regimes, information disclosure requirements, and investor structures compared to the Shanghai and Shenzhen stock exchanges.

State-owned Assets Supervision and Administration Commission of the State Council

A Chinese government agency responsible for supervising state-owned enterprises. It has issued the China Chengtong ESG Evaluation System and Guiding Opinions on Central Enterprises Fulfilling Social Responsibilities, shaping the institutional environment for ESG development in China.

Asset Management Association of China

A self-regulatory organization for the asset management industry in China. It released the first ESG Responsible Investment Survey in 2017, promoting the integration of ESG considerations into domestic investment practices.

China Securities Regulatory Commission

The securities regulatory authority in China. It revised the Code of Corporate Governance for Listed Companies in 2018, formally establishing an ESG information disclosure framework, and regulating ESG related practices of listed companies.

United Nations Environment Programme

A United Nations agency that released the report "Who Cares Wins" in 2004, formally introducing the ESG concept and advocating the integration of environmental, social, and governance factors into corporate strategic investment decisions.

United Nations Principles for Responsible Investment

An initiative jointly launched by UNEP and the UN Global Compact in 2006, aiming to embed ESG considerations into investment processes and align capital market practices with sustainable development goals, marking a milestone in global ESG development.

Carbon Border Adjustment Mechanism

A policy of the European Union requiring exporting enterprises to account for carbon emissions embedded in their products, incentivizing enterprises in global supply chains to improve environmental management practices and align with low-carbon transition goals.

Sustainable Development Goals

A set of global goals adopted by the United Nations to guide sustainable development, covering poverty reduction, environmental protection, and social equity. It has prompted governments to formulate relevant policies (e.g., carbon neutrality goals) and influenced enterprises' ESG strategies and practices.

LIST OF SEMINARS

1. UFE Development Seminar-I, “Discussion on approval of dissertation topic”, May 5, 2025
2. UFE Development Seminar-II, “Discussion on research methodology”, June 5, 2025
3. UFE Research Seminar, “Discussion on the research progress and challenges encountered”, January 15, 2026
4. UFE Grand Seminar, “Discussion on research findings”, March 23, 2026

ABSTRACT

This dissertation examines how intelligent manufacturing affects corporate ESG performance in the context of China, where industrial upgrading and the environmental, social and governance (ESG) system are developing simultaneously. Based on panel data of Chinese A-share listed companies from 2015 to 2023, this study adopts a mixed-method research design, combining two-way fixed effects panel regression analysis, robustness and endogeneity tests, mediation effect analysis, heterogeneity analysis, and case study methods. Within the empirical analysis framework, this dissertation further investigates four mediating mechanisms: information transparency, green technological innovation, financing constraints, and collaborative governance. The empirical results show that intelligent manufacturing has a statistically significant and strong positive effect on corporate ESG performance. This conclusion remains robust and reliable after being tested through alternative variable measurements, PSM-DID analysis, and System GMM model estimation. The mechanism analysis results indicate that intelligent manufacturing contributes to the improvement of corporate ESG performance by enhancing information transparency, strengthening green innovation capability, improving financing conditions, and promoting governance coordination. The heterogeneity analysis results show that the positive effect of intelligent manufacturing on ESG performance is more pronounced among enterprises located in non-western regions, high-tech enterprises, and companies listed on the Shanghai and Shenzhen stock exchanges. The qualitative case studies of Haier, Midea, CATL, and Seres further support the econometric results at the practical level and clearly demonstrate the organizational mechanisms and operational processes through which intelligent manufacturing affects corporate ESG performance. The innovation of this study lies in examining the impact of intelligent manufacturing on ESG performance within a multidimensional and integrated analytical framework. This dissertation demonstrates that intelligent manufacturing is not only a technological upgrade, but also a broad organizational transformation with strategic significance for sustainable development.

Keywords: intelligent manufacturing; corporate ESG performance; sustainable development; information transparency; green technological innovation; Chinese listed companies.

ХУРААНГУЙ

Энэхүү диссертаци аж үйлдвэрийн шинэчлэл болон байгаль орчин, нийгэм, засаглалын (ESG) тогтолцоо зэрэгцэн эрчимжиж буй БНХАУ-ын нөхцөлд ухаалаг үйлдвэрлэл нь аж ахуйн нэгжийн ESG гүйцэтгэлд хэрхэн нөлөөлж буйг судалсан болно. 2015-2023 оны Хятадын А ангиллын хөрөнгийн биржид бүртгэлтэй компаниудын панел өгөгдөлд тулгуурлан энэхүү судалгааны дизайнаа холимог арга зүйгээр боловсруулсан бөгөөд үүнд хоёр хүчин зүйлт тогтмол нөлөөний панел регрессийн шинжилгээ, тогтвортой байдлын болон эндоген байдлын шалгалт, зуучлагч нөлөөний шинжилгээ, гетероген шинжилгээ, мөн кейс судалгааны аргуудыг хослуулан хэрэглэв. Эмпирик шинжилгээний хүрээнд мэдээллийн ил тод байдал, ногоон технологийн инноваци, санхүүжилтийн хязгаарлалт, хамтын засаглалын уялдаа гэсэн дөрвөн зуучлагч механизмыг цаашид нарийвчлан авч үзсэн болно. Эмпирик шинжилгээний үр дүнгээс харахад, ухаалаг үйлдвэрлэл нь аж ахуйн нэгжийн ESG гүйцэтгэлд статистикийн хувьд ач холбогдол бүхий хүчтэй эерэг нөлөө үзүүлж байгааг тогтоосон. Энэхүү дүгнэлт нь хувьсагчийн өөр хувилбар хэмжүүрүүдийг ашигласан баталгаажуулалтын шинжилгээ, PSM-DID шинжилгээ, мөн System GMM загварын үнэлгээгээр тус тус шалгахад ч тогтвортой бөгөөд найдвартай хэвээр байгааг нотолсон болно. Механизмын шинжилгээний үр дүнгээс үзэхэд, ухаалаг үйлдвэрлэл нь мэдээллийн ил тод байдлыг сайжруулах, ногоон инновацийн чадавхыг бэхжүүлэх, санхүүжилтийн нөхцөлийг сайжруулах, засаглалын уялдаа нэмэгдүүлэх замаар ESG гүйцэтгэлийг дээшлүүлэхэд хувь нэмэр оруулж байгааг харуулж байна. Гетероген шинжилгээний үр дүнгээс харахад, ухаалаг үйлдвэрлэлийн ESG гүйцэтгэлийг сайжруулах нөлөө нь баруун бус бүс нутагт үйл ажиллагаа явуулж буй аж ахуйн нэгжүүд, өндөр технологид суурилсан компаниуд, мөн Шанхай болон Шэньжэний хөрөнгийн биржид бүртгэлтэй байгууллагуудад илүү хүчтэй илэрсэн. Haier, Midea, CATL болон Seres компанийн чанарын кейс судалгааны үр дүн нь эконометрик шинжилгээний үр дүнг практик түвшинд бататгаж, ухаалаг үйлдвэрлэл нь байгууллагын ESG гүйцэтгэлд ямар зохион байгуулалтын механизм, үйл явцаар дамжин нөлөөлж буйг тодорхой харуулсан болно. Энэхүү судалгааны шинэлэг тал нь ухаалаг үйлдвэрлэлийн ESG гүйцэтгэлд үзүүлэх нөлөөллийг олон хэмжээс бүхий нэгдмэл аналитик хүрээнд судалсанд оршино. Энэхүү диссертацийн судалгаа нь ухаалаг үйлдвэрлэл нь зөвхөн технологийн шинэчлэл бус, харин тогтвортой хөгжилд стратегийн ач холбогдол бүхий байгууллагын өргөн хүрээтэй шилжилт болохыг нотлон харуулж байна.

Түлхүүр үгс: ухаалаг үйлдвэрлэл; аж ахуйн нэгжийн ESG гүйцэтгэл; тогтвортой хөгжил; мэдээллийн ил тод байдал; ногоон технологийн инноваци; Хятадын хөрөнгийн биржид бүртгэлтэй компаниуд.

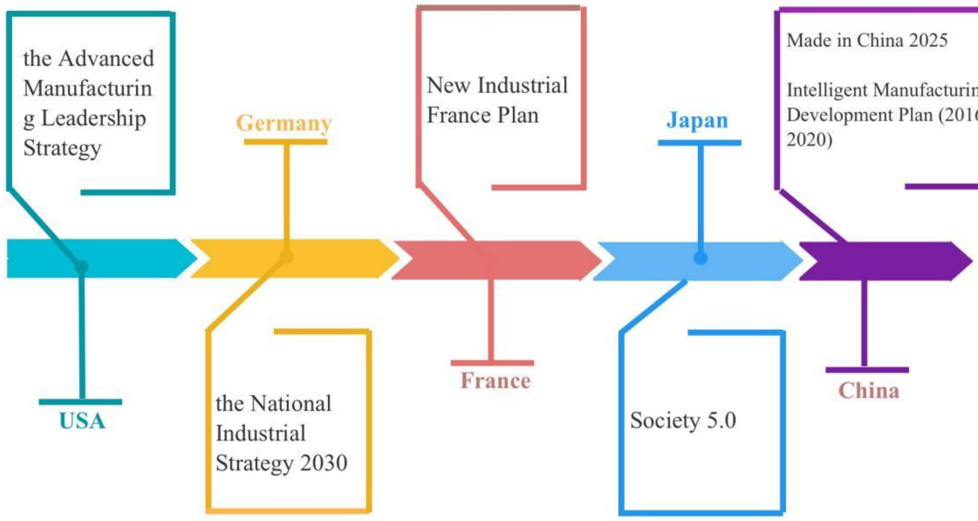
INTRODUCTION

Research Background

In the context of the digital economy and the ongoing wave of industrial transformation, the global manufacturing sector is experiencing a profound restructuring driven by digitalization, interconnection, automation, and intelligence. Against this backdrop, intelligent manufacturing has gradually evolved from a narrowly defined production technology into a strategic approach to industrial upgrading, organizational renewal, and sustainable development. For contemporary manufacturing enterprises, competitiveness is no longer determined solely by production scale or cost efficiency. Increasingly, it also depends on whether enterprises are able to integrate advanced technologies into production and management systems in ways that improve efficiency, strengthen adaptability, and respond effectively to mounting environmental and governance pressures. In this sense, intelligent manufacturing has become a critical pathway through which manufacturing enterprises seek to reconcile technological advancement with long-term sustainable value creation.

From an international perspective, major industrial economies have already identified intelligent manufacturing as a key instrument for enhancing industrial competitiveness and reinforcing the resilience of modern production systems. Whether framed in terms of Industry 4.0, smart factories, or digitally integrated manufacturing ecosystems, the common emphasis lies in the use of advanced information technologies to transform traditional production modes and improve responsiveness, precision, and sustainability. Under these conditions, manufacturing transformation is no longer viewed merely as a technical issue of process optimization; rather, it is increasingly associated with the broader reallocation of production factors, the upgrading of industrial chains, and the pursuit of greener and more resilient development. As a result, for many enterprises, intelligent manufacturing is becoming not only a means of responding to technological disruption and intensified market competition, but also a practical response to stricter environmental expectations and expanding stakeholder scrutiny.

Figure 1.1 Major national strategic initiatives promoting intelligent manufacturing in leading economies



Source: developed by the author

Figure 1.1 shows that major economies have incorporated intelligent manufacturing into their national development agendas through different strategic initiatives, including the Advanced Manufacturing Leadership Strategy in the United States, the National Industrial Strategy 2030 in Germany, the New Industrial France Plan in France, Society 5.0 in Japan, and *China's Made in China 2025* together with the Intelligent Manufacturing Development Plan (2016-2020). Although these policy frameworks differ in their emphasis, they share a common objective of promoting industrial modernization through intelligent production, technological upgrading, and digital transformation. This policy convergence indicates that intelligent manufacturing has become a structurally important force in contemporary industrial development and provides an important macro background for examining its broader economic and sustainability implications.

Within this broader transformation, China has developed a particularly distinctive pathway in which intelligent manufacturing is closely embedded in national industrial strategy. Since the issuance of *Made in China 2025*, intelligent manufacturing has been explicitly positioned as a principal direction for the transformation and upgrading of the manufacturing sector. This strategic orientation was subsequently reinforced through the *14th Five-Year Plan for Intelligent Manufacturing Development*, which called for the accelerated advancement of digitalized, networked, and intelligent manufacturing systems, while also emphasizing the coordinated development of high-end, intelligent, and green manufacturing. These policy arrangements indicate that intelligent manufacturing in China should not be understood as an isolated technological initiative. Rather, it has become a central component of broader national objectives, including industrial modernization, high-quality development, green transition, and the cultivation of new productive forces. In other words, intelligent manufacturing has moved from a policy vision to an increasingly concrete and systematic process of implementation within China's real economy.

The significance of this policy trajectory has become even more pronounced in light of the dual pressures of economic restructuring and low-carbon transition. Chinese manufacturing enterprises are now expected not only to sustain competitiveness in a rapidly changing global environment, but also to align with national goals related to carbon peaking, carbon neutrality, industrial upgrading, and green development. Under these conditions, intelligent manufacturing is widely regarded as a practical mechanism for improving production efficiency, reducing energy and resource waste, strengthening process control, and facilitating cleaner production. More importantly, the integration of intelligent technologies into production, management, and service systems may alter the way enterprises organize operations, process information, monitor activities, and coordinate internal and external relationships. This suggests that intelligent manufacturing is not merely a matter of introducing new equipment or digital tools; it constitutes a deeper organizational transformation with implications that may extend beyond traditional operational outcomes.

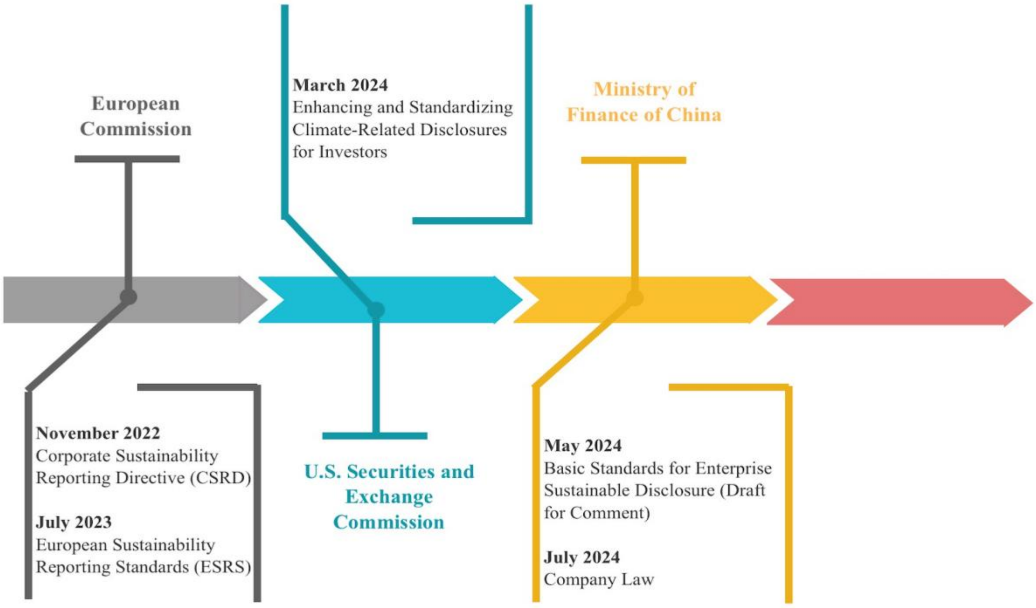
To position the study more precisely, it is necessary to clarify what is meant by intelligent manufacturing in this dissertation and why it deserves analytical attention. In this dissertation, intelligent manufacturing refers to a firm-level transformation process in which advanced manufacturing technologies are deeply integrated with next-generation digital and information technologies across the full manufacturing life-cycle. It extends beyond the simple introduction of automation equipment, industrial robots, or isolated digital tools. Rather, it involves the coordinated reconfiguration of production systems, information flows, decision-making processes, and organizational arrangements through technologies such as industrial internet platforms, data-driven control systems, intelligent equipment, real-time monitoring, and algorithm-based optimization. In this sense, intelligent manufacturing is treated not merely as a technological upgrade, but as a broader organizational capability through which enterprises improve production efficiency, optimize resource allocation, enhance process transparency, strengthen adaptive decision-making, and increase coordination across internal and external activities.

This broader conceptualization is important for the present study for two reasons. First, it provides a more appropriate theoretical basis for examining why intelligent manufacturing may influence enterprise ESG performance. If intelligent manufacturing were understood only as equipment upgrading or automation substitution, its relevance to environmental performance, information transparency, stakeholder responsiveness, and governance improvement would be difficult to explain. By contrast, once it is understood as a comprehensive transformation of production organization, information processing, and managerial coordination, its potential ESG implications become much clearer. Second, this definition is also important from a methodological perspective, because it implies that intelligent manufacturing should be measured in a way that captures its composite and firm-level nature, rather than through a single input, a binary policy indicator, or a purely disclosure-based proxy. For this reason, the dissertation treats intelligent manufacturing as a multidimensional enterprise capability and subsequently adopts a continuous firm-level index to reflect differences in the extent to which enterprises convert intelligent manufacturing inputs into effective operational outcomes.

Meanwhile, as global climate change intensifies, social responsibility awareness increases, and corporate governance modernization accelerates, enterprises' Environmental, Social, and Governance (ESG) performance has gradually become an important benchmark for evaluating long-term firm value and development quality. ESG has rapidly developed into an increasingly influential framework for evaluating corporate sustainability, non-financial performance, and long-term development quality. In the Chinese context, particularly under the constraints of the "dual-carbon" goals, the Chinese government has continuously strengthened environmental regulation and non-financial information disclosure requirements, while capital markets have shown a markedly increased focus on enterprises' ESG performance. The growing importance of ESG is closely associated with the broader policy agenda of ecological civilization, green transformation, and the modernization of corporate governance. As regulators, capital markets, and the public have become more concerned with environmental responsibility, social accountability, and governance quality, ESG has gradually shifted from a relatively soft evaluative concept to a more institutionalized governance standard. This shift is reflected in the strengthening of sustainability disclosure requirements and the growing expectation that listed companies should demonstrate not only financial soundness, but also broader responsibility and transparency in their operations. Accordingly, ESG is increasingly relevant to corporate legitimacy, market recognition, investor confidence, and resource acquisition. Consequently, corporate ESG performance has gradually evolved from a "non-financial disclosure tool" into an important constraint affecting financing conditions, investor structure, and market valuation, with ESG considerations shifting from "soft constraints" to increasingly binding "hard constraints."

As shown in Figure 1.2, ESG related disclosure requirements have developed rapidly across major jurisdictions. The European Union has advanced corporate sustainability regulation through the Corporate Sustainability Reporting Directive and the European Sustainability Reporting Standards; the U.S. Securities and Exchange Commission has promoted the enhancement and standardization of climate-related disclosures for investors; and China has accelerated the construction of its own sustainability disclosure framework through the Basic Standards for Enterprise Sustainable Disclosure and the revised Company Law. These developments indicate that ESG governance is becoming increasingly institutionalized and standardized. As a result, enterprise sustainability performance is now evaluated within a more explicit regulatory and governance framework.

Figure 1.2 Recent regulatory developments in enterprise ESG disclosure



Source: developed by the author

Recent policy developments further highlight the institutionalization of ESG governance in China. The issuance of the *Self-Regulatory Guidelines No. 14-Sustainability Report (Trial)* by the Shanghai Stock Exchange in 2024 marked an important step toward more standardized sustainability disclosure among listed companies. In the same year, the release of the *Basic Standard for Enterprise Sustainability Disclosure (Trial)* further signaled the gradual formation of a nationally coordinated sustainability disclosure framework. These developments indicate that ESG in China is no longer merely a voluntary signaling mechanism used for reputation management. Instead, it is increasingly becoming part of a more structured governance and disclosure regime that affects how firms are evaluated by regulators, investors, and other stakeholders. In this policy environment, improving ESG performance is not only a matter of image enhancement, but also an increasingly important component of compliance, transparency, and long-term competitiveness.

Enterprise ESG performance, however, is shaped by a wide range of interrelated factors rather than by any single determinant. Existing studies suggest that ESG outcomes are influenced by internal corporate conditions, including ownership structure, governance quality, managerial capability, financing constraints, innovation capacity, and resource allocation efficiency, while they are also affected by external factors such as regulatory pressure, industry attributes, market competition, and the broader institutional environment. This indicates that ESG performance is embedded in a complex organizational and environmental system in which strategic choices, operating conditions, and external constraints interact simultaneously. Precisely because the determinants of ESG performance are so diverse, it becomes especially important to identify those factors that are capable of exerting systematic and multidimensional effects on firm behavior. In this regard, focusing on intelligent manufacturing is particularly meaningful. Unlike many traditional determinants that affect only certain aspects of ESG or operate mainly through external pressure, intelligent manufacturing represents a deep transformation of the production chain, management system, and coordination mechanism of the firm itself. It may improve environmental outcomes through cleaner production, resource conservation, and efficiency enhancement; it may also affect social and governance performance by strengthening information transparency, improving product and operational quality, facilitating collaborative management, and enhancing firms' responsiveness to stakeholder expectations. Existing research has also noted that studies on ESG determinants have paid relatively greater attention to internal firm characteristics and general institutional conditions, whereas the role of technology-driven transformation, especially intelligent manufacturing as a core feature of the new round of industrial upgrading, remains insufficiently examined. For this reason, concentrating on the impact of intelligent manufacturing on enterprise ESG performance not only responds to an important gap in the literature, but also captures a highly relevant mechanism through which Chinese manufacturing firms may simultaneously pursue industrial upgrading and sustainable development

It is precisely at the intersection of these two major development, the strategic promotion of intelligent manufacturing and the institutional strengthening of ESG governance, that the present dissertation is situated. On the one hand, manufacturing enterprises are being encouraged to accelerate intelligent transformation in order to improve productivity, innovation capability, and resilience. On the other hand, they are simultaneously facing stronger expectations to enhance environmental performance, strengthen social responsibility, and respond to increasingly formalized sustainability disclosure requirements. Under these conditions, intelligent manufacturing may provide enterprises with an important internal basis for achieving better ESG performance. Compared with traditional production upgrading, intelligent manufacturing may generate broader organizational effects by improving process transparency, supporting cleaner production, facilitating resource optimization, and strengthening managerial coordination. This makes it particularly relevant to the study of how manufacturing transformation can contribute to sustainable corporate development.

Existing empirical studies have begun to suggest that intelligent manufacturing may generate broader sustainability implications beyond conventional economic and operational outcomes. Emerging evidence indicates that intelligent manufacturing can contribute to enterprise ESG performance by improving production efficiency, facilitating cleaner production, enhancing information processing capacity, and strengthening organizational coordination. At the same time, some studies suggest that the effects of intelligent manufacturing may vary across firms with different ownership structures, industrial characteristics, regional conditions, and institutional environments. These findings imply that intelligent manufacturing is not merely a production-side technological upgrade, but may also have important consequences for corporate sustainability and governance.

However, the existing literature still leaves several important issues unresolved. First, the overall effect of intelligent manufacturing on enterprise ESG performance has not yet been firmly established within a sufficiently integrated analytical framework. A large proportion of earlier studies on intelligent manufacturing focused primarily on outcomes such as production efficiency, innovation output, operational performance, or firm value, while relatively limited attention was paid to comprehensive sustainability outcomes captured by the ESG framework. Even in the emerging studies that directly address ESG related consequences, the evidence remains relatively fragmented in terms of research design, variable operationalization, and analytical scope.

Second, the internal mechanisms through which intelligent manufacturing affects enterprise ESG performance remain under-explored. Although prior studies have provided preliminary discussions of channels such as transparency enhancement, green innovation, resource optimization, and governance improvement, these mechanisms have not yet been systematically incorporated into a unified micro-level empirical framework. As a result, the literature still lacks a sufficiently clear explanation of how intelligent manufacturing is translated into improvements in the environmental, social, and governance dimensions of firm performance.

Third, the heterogeneous effects of intelligent manufacturing on enterprise ESG performance have not been adequately clarified. In the Chinese context, enterprises operate under markedly different regional development conditions, technological attributes, and capital market environments. These contextual differences may shape enterprises' capacity to implement intelligent manufacturing and to convert technological upgrading into ESG improvement. Nevertheless, existing studies have not yet provided sufficient evidence on whether, and under what conditions, the ESG effects of intelligent manufacturing vary systematically across different types of enterprises.

Taken together, these limitations indicate a clear research gap in the current literature. There remains a lack of systematic firm-level evidence capable of identifying the overall effect, uncovering the underlying mechanisms, and clarifying the heterogeneous conditions under which intelligent manufacturing influences enterprise ESG performance. Addressing this gap is important not only for strengthening the theoretical linkage between intelligent manufacturing and corporate sustainability research, but also for providing a more solid empirical basis for policy design and managerial decision-making in the context of China's high-quality development agenda.

Against this background, this dissertation takes Chinese A-share listed companies from 2015 to 2023 as the research object and systematically examines whether intelligent manufacturing significantly improves enterprise ESG performance, through what mechanisms this effect occurs, and under what conditions it becomes more pronounced. By doing so, this dissertation seeks to provide a more coherent empirical explanation of how intelligent transformation contributes to sustainable corporate development in China.

Problem Statement

Existing research still does not adequately explain whether intelligent manufacturing improves enterprise ESG performance, through what mechanisms such improvement occurs, and under what conditions the effect varies across enterprises. This unresolved issue constitutes the central research problem of this dissertation.

The significance of this problem arises from a mismatch between two developments that are now advancing in parallel. On the one hand, intelligent manufacturing has become a major route through which manufacturing enterprises pursue higher productivity, stronger innovation capability, greater operational resilience, and sustained competitiveness. Its significance lies not only in the adoption of advanced technologies, but also in the broader reorganization of production processes, information flows, managerial coordination, and resource allocation. On the other hand, enterprise ESG performance has become an increasingly influential measure of corporate sustainability, legitimacy, and long-term value creation. Enterprises are no longer evaluated solely in terms of efficiency and financial outcomes; they are also judged by their environmental responsibility, social performance, and governance quality. In China, this convergence is particularly pronounced, as industrial upgrading, green transformation, and high-quality development are being promoted simultaneously.

Yet the literature has not kept pace with this convergence. Research on intelligent manufacturing has largely concentrated on outcomes such as production efficiency, quality improvement, cost reduction, innovation performance, and firm value. Research on enterprise ESG performance, by contrast, has mainly examined determinants such as ownership structure, governance arrangements, financial conditions, regulatory pressure, and broad forms of digital transformation. As a result, the relationship between intelligent manufacturing and enterprise ESG performance remains theoretically under-integrated and empirically under-specified. The problem is not simply that these two topics have often been studied separately. More fundamentally, the existing literature still does not provide a convincing explanation of whether intelligent manufacturing can generate sustainability-related benefits at the enterprise level, how such benefits might emerge, and why they may not emerge uniformly across enterprises.

This gap matters because, without resolving it, an important explanatory link remains missing in current scholarship. If intelligent manufacturing is studied only in terms of efficiency, innovation, or market performance, its broader implications for sustainable corporate development remain obscured. If enterprise ESG performance is analyzed without considering the role of production-side technological transformation, then ESG research overlooks one potentially important source of change within the enterprise. In other words, failing to address this problem leaves a conceptual disconnect between research on technological upgrading and research on sustainability governance. It also weakens the empirical basis on which enterprises and policymakers seek to align intelligent transformation with ESG improvement.

More specifically, the unresolved problem has three closely connected dimensions. The first concerns the overall effect: it remains insufficiently established whether intelligent manufacturing significantly improves enterprise ESG performance at the firm level. The second concerns the mechanism of influence: even where a positive relationship is suggested, the internal processes through which intelligent manufacturing may affect enterprise ESG performance have not been systematically identified. The third concerns heterogeneous effects: enterprises differ substantially in regional environment, technological attributes, and market setting, yet the conditions under which intelligent manufacturing is more or less likely to generate ESG gains remain unclear.

These unresolved issues are especially important in the Chinese context. China's manufacturing sector is under simultaneous pressure to move upward in technological capability, reduce environmental costs, respond to growing stakeholder expectations, and adapt to increasingly institutionalized ESG norms. Under such conditions, clarifying the relationship between intelligent manufacturing and enterprise ESG performance is not merely an academic exercise. It is essential for understanding whether intelligent transformation can serve as a practical pathway to more sustainable corporate development, and for identifying the organizational and contextual conditions under which that pathway is most effective.

Accordingly, this dissertation defines its central research problem as follows: whether intelligent manufacturing improves enterprise ESG performance, through what mechanisms such an effect is produced, and under what conditions it becomes stronger, weaker, or uneven across enterprises. By addressing this problem, this dissertation seeks to explain how technological transformation in manufacturing may extend beyond operational upgrading and become part of an enterprise's broader sustainability capability.

Research Questions

Once the central research problem has been clearly defined, it must be analytically decomposed into a set of research questions that can guide the empirical investigation. The problem addressed in this dissertation has three interconnected dimensions: the existence of the relationship between intelligent manufacturing and enterprise ESG performance, the mechanisms through which that relationship operates, and the conditions under which its effects may differ across enterprises. Accordingly, this dissertation develops three interrelated research questions. These questions are structured in a progressive sequence, moving from the identification of the main effect, to the explanation of the underlying mechanisms, and finally to the clarification of heterogeneous effects. In combination, they form the core analytical framework through which the central research problem is examined.

RQ1: Does intelligent manufacturing significantly improve enterprise ESG performance?

This question addresses the most fundamental issue in this dissertation. Before the relationship can be explained in greater depth, it must first be established whether intelligent manufacturing exerts a statistically significant and substantively meaningful influence on enterprise ESG performance at the firm level. This question therefore focuses on identifying the existence, direction, and magnitude of the overall effect, while taking into account relevant enterprise characteristics and external conditions. Answering this question is essential because it determines whether intelligent manufacturing can be understood not only as a source of operational or technological upgrading, but also as a factor shaping broader sustainability outcomes within the enterprise.

RQ2: Through what mechanisms does intelligent manufacturing affect enterprise ESG performance?

If intelligent manufacturing is found to improve enterprise ESG performance, the next question is how this improvement occurs. This question seeks to uncover the internal logic of the relationship by identifying the principal channels through which intelligent manufacturing may influence enterprise ESG performance. In particular, the dissertation examines whether information transparency, green technological innovation, financing constraints, and synergistic governance serve as the main mechanisms linking intelligent manufacturing to ESG improvement. The purpose of this question is to move beyond a simple finding of correlation or effect and to explain how technological and organizational transformation at the firm level may be translated into environmental, social, and governance gains.

RQ3: Under what conditions does the impact of intelligent manufacturing on enterprise ESG performance vary?

The effect of intelligent manufacturing is unlikely to be uniform across all enterprises. Chinese enterprises differ substantially in their regional environment, technological attributes, and market setting, and these differences may shape both the implementation of intelligent manufacturing and its sustainability consequences. This question therefore examines whether the relationship between intelligent manufacturing and enterprise ESG performance varies systematically across different contexts, with particular attention to regional location, technological characteristics, and listing-board segments. By addressing this question, the dissertation seeks to clarify the heterogeneous effects of intelligent manufacturing and to identify the conditions under which its contribution to enterprise ESG performance is more pronounced, more limited, or more uneven.

Taken together, these three research questions form a single analytical sequence rather than a set of separate inquiries. The first establishes whether there is a relationship that requires explanation. The second examines the mechanisms through which that relationship operates. The third identifies the contexts in which the relationship is more or less likely to emerge. In combination, they enable the dissertation to move from problem identification to empirical explanation in a structured and logically consistent way.

Research Purpose

This dissertation aims to explain whether and how intelligent manufacturing contributes to enterprise ESG performance in the Chinese context. Specifically, it seeks to establish the overall effect of intelligent manufacturing on enterprise ESG performance, identify the main organizational mechanisms through which this effect operates, and clarify the conditions under which the effect becomes stronger or weaker across enterprises.

A further aim of the dissertation is to connect research on intelligent manufacturing with research on enterprise sustainability within a unified analytical framework. Rather than treating technological upgrading and ESG governance as separate areas of inquiry, this dissertation examines how they intersect at the firm level and how intelligent transformation may become associated with broader sustainability outcomes.

This dissertation also makes substantive use of the Chinese context, where industrial upgrading, green transition, and ESG institutionalization are advancing simultaneously. In this respect, the study seeks not only to provide firm-level empirical evidence, but also to offer a more coherent explanation of how intelligent transformation may contribute to sustainable corporate development under conditions of regional, technological, and market heterogeneity.

Ultimately, this dissertation is intended to be both academically meaningful and practically relevant: academically, by deepening understanding of the relationship between intelligent manufacturing and enterprise ESG performance; and practically, by providing a more reliable basis for enterprises and policymakers seeking to align intelligent transformation with sustainability improvement.

Research Objectives

In order to translate the above research purpose into a set of concrete and empirically examinable tasks, this dissertation formulates four research objectives. These objectives are derived directly from the central research problem and the corresponding research questions, and together they provide the operational structure for the empirical investigation that follows. They are organized according to the internal logic of the study: first, to establish whether intelligent manufacturing has a significant relationship with enterprise ESG performance; second, to identify the mechanisms through which that relationship operates; third, to examine whether the relationship varies across different contexts; and finally, to integrate these findings into a broader firm-level explanation of sustainable transformation. In this way, the research objectives do not simply restate the research questions. Rather, they specify the concrete analytical tasks through which the dissertation's broader purpose is pursued.

RO1: To establish whether intelligent manufacturing has a significant effect on enterprise ESG performance.

This objective focuses on identifying the direction, magnitude, and statistical significance of the relationship between intelligent manufacturing and enterprise ESG performance at the firm level. It addresses the foundational task of determining whether intelligent manufacturing can be understood not only as a driver of operational and technological upgrading, but also as a factor associated with broader sustainability outcomes within the enterprise.

RO2: To examine the mechanisms through which intelligent manufacturing influences enterprise ESG performance.

This objective seeks to identify the principal channels through which intelligent manufacturing may be translated into improved enterprise ESG performance. In particular, it investigates whether information transparency, green technological innovation, financing constraints, and synergistic governance operate as the main mechanisms linking intelligent manufacturing to ESG improvement. By doing so, it moves beyond the identification of a general effect and addresses the explanatory question of how technological and organizational transformation generates sustainability-related outcomes.

RO3: To test whether the effect of intelligent manufacturing on enterprise ESG performance varies across different contexts.

This objective examines whether the relationship between intelligent manufacturing and enterprise ESG performance differs systematically across enterprises operating under different conditions. Specifically, it investigates variation associated with regional location, technological attributes, and listing-board segments, thereby clarifying the heterogeneous effects of intelligent manufacturing and identifying the contexts in which its sustainability consequences are more pronounced, more limited, or more uneven.

RO4: To integrate the findings on overall effect, mechanism, and heterogeneous effects into a firm-level explanatory framework of sustainable transformation.

This objective aims to synthesize the empirical results of the dissertation into a coherent explanation of how intelligent manufacturing contributes to sustainable corporate development in China. Rather than treating the main effect, mechanism analysis, and heterogeneity analysis as separate empirical exercises, it seeks to connect them within a unified interpretive framework that explains how intelligent transformation may become part of an enterprise's broader sustainability capability.

To conclude, these objectives reflect the full analytical trajectory of the dissertation. The dissertation first establishes whether intelligent manufacturing affects enterprise ESG performance, then explains how that influence is produced, and finally examines the conditions under which it varies across enterprises. On this basis, it develops an integrated empirical explanation of how intelligent manufacturing may contribute to sustainable corporate development in the Chinese context.

Research Hypothesis

1. Intelligent Manufacturing and Enterprise ESG Performance

Through the deep integration of next-generation information technologies and advanced manufacturing technologies, intelligent manufacturing significantly transforms enterprises' production organization modes and resource allocation patterns. On the one hand, intelligent manufacturing enhances the precision and intelligence of production processes, thereby reducing energy consumption and pollutant emissions, which is conducive to improving enterprises' environmental performance. On the other hand, it may also strengthen enterprises' information processing capability, operational transparency, and governance efficiency through digital information systems and data platforms, thereby supporting broader ESG improvement. While the effects of intelligent manufacturing may not be entirely uniform across all ESG sub-dimensions, enterprise ESG performance is treated in this dissertation as a composite measure of environmental, social, and governance outcomes; accordingly, H1 is formulated at the level of the overall firm-level effect of intelligent manufacturing rather than at the level of separate sub-dimensional predictions. In the Chinese context, where intelligent manufacturing is promoted together with green transformation, disclosure standardization, and high-quality development, it remains reasonable to hypothesize that intelligent manufacturing will improve enterprise ESG performance on an overall basis. Based on the above analysis, the following hypothesis is proposed:

H1: Intelligent manufacturing has a positive impact on enterprise ESG performance.

2. Mediating Effect of Information Transparency

The advancement of intelligent manufacturing is typically accompanied by upgrades in information systems, the construction of data platforms, and the digital restructuring of business processes. These changes enhance the accuracy and timeliness of enterprises' information collection, processing, and disclosure, thereby alleviating information asymmetry between firms and external investors. Improvements in information transparency not only strengthen corporate governance constraints but may also lead to better corporate behavior in environmental protection, social responsibility fulfillment, and governance practices, ultimately contributing to enhanced enterprise ESG performance. Based on this reasoning, the following hypothesis is proposed:

H2: Intelligent manufacturing indirectly improves enterprise ESG performance by enhancing enterprises' information transparency.

H2a: Intelligent manufacturing is positively associated with enterprises' information transparency.

H2b: Enterprises' information transparency is positively associated with enterprise ESG performance, holding intelligent manufacturing constant.

3. Mediating Effect of Green Technological Innovation

By promoting the deep integration of digital technologies and production technologies, intelligent manufacturing provides an important technological foundation for enterprises to engage in green technology research and development as well as process improvement. Intelligent production processes enable firms to more effectively identify opportunities for energy conservation and emission reduction, thereby fostering green product and green process innovation. As green innovation activities constitute a critical pathway through which enterprises improve environmental performance, fulfill social responsibilities, and enhance long-term governance capacity, intelligent manufacturing may ultimately contribute to better overall ESG performance through this channel. Based on the above analysis, the following hypothesis is proposed:

H3: Intelligent manufacturing indirectly improves enterprise ESG performance by promoting enterprises' green technological innovation.

H3a: Intelligent manufacturing is positively associated with enterprises' green technological innovation.

H3b: Enterprises' green technological innovation is positively associated with enterprise ESG performance, holding intelligent manufacturing constant.

4. Mediating Effects of Financing Constraints

Financing constraints capture the financial resource condition under which intelligent manufacturing can be translated into enterprise ESG improvement. Both intelligent manufacturing and ESG improvement require sustained financial support. On the one hand, intelligent manufacturing usually involves substantial upfront investment in intelligent equipment, digital infrastructure, automation systems, data platforms, and employee training. On the other hand, ESG improvement also requires continuous investment in cleaner production, environmental monitoring, employee protection, supply-chain responsibility, information disclosure, and governance optimization. Therefore, the relationship between intelligent manufacturing and ESG performance depends not only on technological capability, but also on whether enterprises have sufficient financial resources to sustain such transformation. From the perspective of financial-resource availability, intelligent manufacturing may influence ESG performance through two related channels. First, intelligent manufacturing may improve production efficiency, operational stability, process traceability, and information transparency, thereby enhancing firms' cash-flow stability and external credit recognition. This can help alleviate financing constraints and increase firms' capacity to invest in ESG related activities. Second, if financing constraints remain severe, the high investment cost of intelligent transformation may weaken firms' ability to continuously allocate resources to environmental, social, and governance improvement. In this sense, financing constraints represent a key transmission mechanism linking intelligent manufacturing, resource allocation, and enterprise ESG performance. Accordingly, the following hypothesis is proposed:

H4: Intelligent manufacturing indirectly improves enterprise ESG performance by alleviating enterprises' financing constraints.

H4a: Intelligent manufacturing is negatively associated with enterprises' financing constraints.

H4b: Enterprises' financing constraints is negatively associated with enterprise ESG performance, holding intelligent manufacturing constant.

5. Mediating Effects of Synergistic Governance

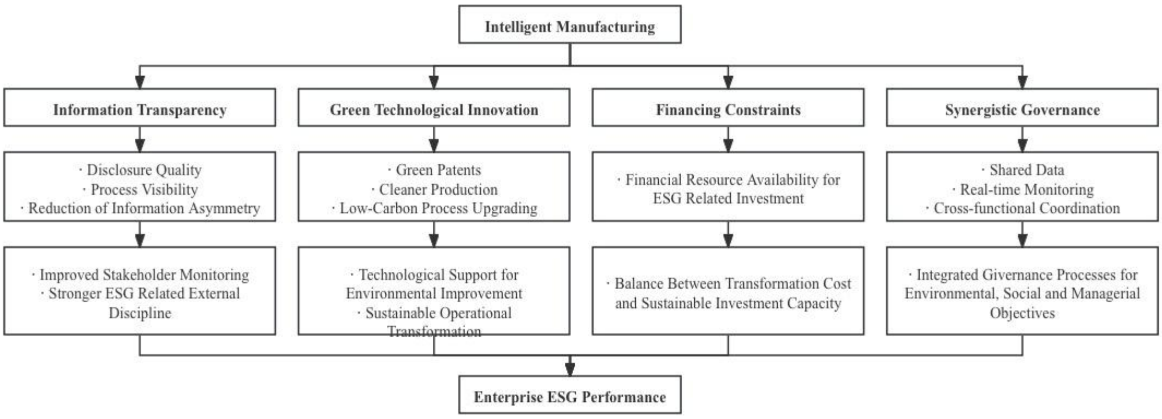
Synergistic governance refers to the enterprise's digitally enabled coordination capability across internal functions and key external interfaces relevant to ESG implementation. In the context of intelligent manufacturing, digital platforms, real-time monitoring, and shared data systems help reduce organizational fragmentation and improve coordination among production, supervision, environmental management, supply-chain operations, and information disclosure. This makes ESG related objectives more executable through shared information, coordinated procedures, and more consistent implementation rules. Therefore, intelligent manufacturing may improve enterprise ESG performance not only through technological upgrading, but also by strengthening synergistic governance as an organizational coordination mechanism. Based on the above analysis, the following hypothesis is proposed:

H5: Intelligent manufacturing indirectly improves enterprise ESG performance by strengthening enterprises’ synergistic governance capacity.

H5a: Intelligent manufacturing is positively associated with enterprises’ synergistic governance capacity.

H5b: Enterprises’ synergistic governance capacity is positively associated with enterprise ESG performance, holding intelligent manufacturing constant.

Figure 1.3 Four Mediating Mechanisms Linking Intelligent Manufacturing and Enterprise ESG Performance



Source: developed by the author

Figure 1.3 summarizes the four mediating mechanisms through which intelligent manufacturing may affect enterprise ESG performance. First, intelligent manufacturing improves information transparency by strengthening data collection, process visibility, and disclosure quality, thereby reducing information asymmetry. Second, intelligent manufacturing promotes green technological innovation by providing digital and technological support for cleaner production, energy-saving processes, and green product development. Third, intelligent manufacturing may affect financing constraints by changing enterprises’ financial-resource conditions. Although intelligent transformation requires substantial upfront investment, it may also improve efficiency, operational stability, and credit recognition, thereby enhancing enterprises’ ability to sustain ESG related investment. Fourth, intelligent manufacturing strengthens synergistic governance by improving cross-functional coordination, real-time monitoring, and shared data-based decision-making. Together, these mechanisms explain how intelligent manufacturing can be translated into environmental, social, and governance improvement at the enterprise level.

6. Heterogeneity Hypotheses-Regional Differences

In the Chinese context, the ESG consequences of intelligent manufacturing are unlikely to be spatially uniform, because enterprises operate under markedly different regional conditions. The key issue is not simply whether enterprises adopt intelligent manufacturing technologies, but whether the surrounding environment enables such technological upgrading to be converted into observable improvements in environmental, social, and governance performance. Compared with enterprises located in Western regions, enterprises in non-Western regions generally benefit from stronger industrial support systems, more developed digital infrastructure, denser supply-chain linkages, and more mature market and regulatory environments. These conditions make it easier for intelligent manufacturing to be embedded in broader processes of transparency enhancement, green innovation, and governance improvement. By contrast, enterprises in Western regions may face weaker complementary conditions for sustaining and scaling such transformation, which can reduce the extent to which intelligent manufacturing is translated into measurable ESG gains. Based on this reasoning, the following hypothesis is proposed:

H6: Compared with enterprises located in western regions, intelligent manufacturing has a stronger positive effect on the ESG performance of enterprises in non-western regions.

7. Heterogeneity Hypotheses-Technology Attributes

High-tech enterprises typically possess stronger technological absorptive capacity and more solid innovation foundations, which enable them to more effectively transform intelligent manufacturing into green innovation outcomes and governance improvements, thereby generating more pronounced ESG effects. Accordingly, intelligent manufacturing is expected to exert a stronger positive influence on enterprise ESG performance in high-tech firms than in non-high-tech enterprises.Based on this reasoning, the following hypothesis is proposed:

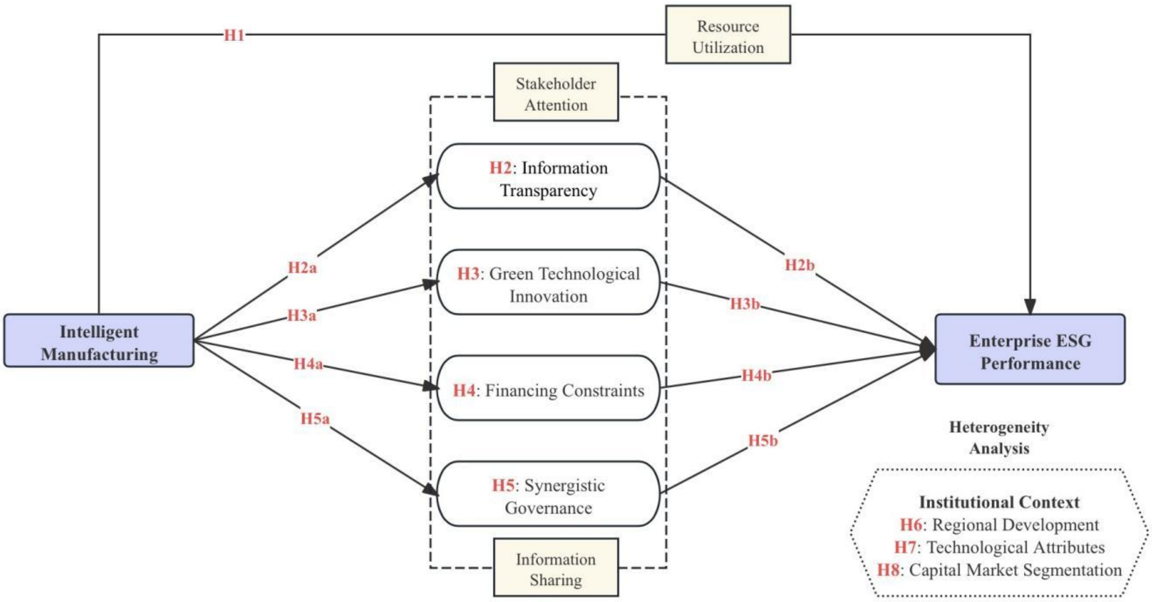
H7: Compared with non-high-tech enterprises, intelligent manufacturing has a more pronounced positive effect on the ESG performance of high-tech enterprises.

8. Heterogeneity Hypotheses-Capital Market Segments

China's multi-tier capital market exhibits institutional differences across listing boards in terms of firm size, information disclosure requirements, and investor structure. Enterprises listed on the Shanghai and Shenzhen stock exchanges are generally subject to more mature governance norms and stronger market discipline, which may enable intelligent manufacturing to be more effectively translated into improvements in enterprise ESG performance. Accordingly, the ESG effects of intelligent manufacturing are expected to be more pronounced for enterprises listed on the Shanghai and Shenzhen stock exchanges. Based on the above reasoning, the following hypothesis is proposed:

H8: Compared with enterprises listed on the Beijing Stock Exchange, intelligent manufacturing has a stronger positive effect on the ESG performance of enterprises listed on the Shanghai and Shenzhen stock exchanges.

Figure 1.4 Research Hypotheses on the Impact of Intelligent Manufacturing on Enterprise ESG Performance



Source: developed by the author

Figure 1.4 illustrates the overall research framework of this dissertation. The figure presents the direct effect of intelligent manufacturing on enterprise ESG performance, the four mediating mechanisms, and the heterogeneity analysis incorporated in this dissertation. Specifically, intelligent manufacturing is proposed to affect enterprise ESG performance directly, while also exerting indirect effects through information transparency, green technological innovation, financing constraints alleviation, and synergistic governance. In addition, the framework highlights the heterogeneous nature of this relationship across different institutional and firm-level contexts, including regional development, technological attributes, and capital market segmentation. This integrated framework provides a systematic conceptual structure for the hypothesis development, empirical design, mechanism testing, and heterogeneity analysis of the dissertation.

Research Methods

To comprehensively examine the impact of intelligent manufacturing on enterprise ESG performance and its underlying mechanisms, this dissertation adopts a mixed-methods research design that integrates literature review, empirical econometric analysis, and case studies. This multi-method approach enhances the robustness, depth, and interpretability of the research findings.

1. Literature review method

This dissertation employs a systematic literature review method to collect, organize, and synthesize relevant domestic and international studies on intelligent manufacturing and corporate ESG performance. By comprehensively reviewing and categorizing existing theoretical and empirical research, this study identifies the main research streams, core findings, and unresolved issues in the current literature. The literature review provides a solid theoretical foundation for defining the research scope, clarifying the research questions, developing hypotheses, and selecting appropriate research methods, thereby ensuring that the study is grounded in established academic discourse while addressing existing research gaps.

2. Empirical analysis method

The core empirical analysis of this study is based on panel data of Chinese A-share listed companies from 2015 to 2023. Using econometric regression techniques, this study systematically examines the impact of intelligent manufacturing on enterprise ESG performance. A two-way fixed effects model is employed to control for unobserved firm-specific heterogeneity and time effects, thereby enhancing the credibility of the estimated results.

To further uncover the internal mechanisms through which intelligent manufacturing affects enterprise ESG performance, this study constructs mediation effect models to analyze the roles of information transparency, green innovation, financing constraints and synergistic governance. By explicitly testing multiple mediating channels, the empirical analysis provides a nuanced understanding of the transmission pathways linking intelligent manufacturing to enterprise ESG outcomes.

In addition, heterogeneity analyses are conducted to examine whether the impact of intelligent manufacturing on enterprise ESG performance varies across enterprises with different characteristics. Specifically, sub-sample regressions are performed based on differences in different regional, technological attributes, and capital market segments. These analyses allow for a more comprehensive assessment of contextual factors that may condition the ESG effects of intelligent manufacturing and provide richer empirical evidence to support the study’s conclusions.

3. Case study method

This dissertation will select four representative enterprises that have implemented intelligent manufacturing, and through the public data system, sort out their intelligent manufacturing practices and changes in ESG performance, extract the specific paths and mechanisms by which intelligent manufacturing affects ESG performance, provide supplementary and verification for empirical research, and explore universal experiences and inspirations.

Case one is Haier Smart Home Co., Ltd.. By developing the COSMOPlat industrial internet platform, Haier has achieved real-time data collection and integrated management across production, quality control, energy consumption, and supply chain operations. Intelligent manufacturing significantly improves the accuracy, timeliness, and traceability of operational and environmental information, thereby reducing information asymmetry between the enterprise and external stakeholders. Enhanced transparency strengthens governance discipline and supports more credible ESG disclosure, particularly in environmental and social responsibility dimensions. This case illustrates that intelligent manufacturing can improve enterprise ESG performance by enhancing information transparency, providing qualitative support for Hypothesis H2.

Case two is Midea Group, which promotes the transformation from traditional manufacturing to intelligent manufacturing through its “intelligent industry” strategy. Midea Group establishes a smart energy management system through intelligent manufacturing to optimize energy efficiency and uses a smart logistics system to optimize transportation efficiency and reduce carbon emissions. In addition, it also promotes green design throughout the product life cycle, promotes resource recycling, and further promotes the development of circular economy. This case illustrates that intelligent manufacturing can improve enterprise ESG performance by enhancing green innovation, providing qualitative support for Hypothesis H3.

Case three is Contemporary Amperex Technology Co., Limited (CATL). Through the extensive deployment of highly automated and intelligent production lines, CATL has significantly enhanced production efficiency, operational stability, and quality consistency. These improvements reduce business risk and strengthen cash flow stability, thereby improving the enterprise’s financial condition. At the same time, intelligent manufacturing enhances market confidence and facilitates access to external financing, including green credit and green bonds. The relaxation of financing constraints enables sustained investment in environmental protection, employee development, and supply chain governance, supporting improved enterprise ESG performance. This case provides qualitative evidence for Hypothesis H4.

Case four is Seres, a technology driven automotive enterprise with new energy vehicles as its core business. It has established a digital carbon management platform through intelligent manufacturing, achieving full lifecycle carbon management and collaborating with upstream and downstream supply chain enterprises to promote green and low-carbon development. At the same time, through the construction of smart factories and photovoltaic power stations, it has achieved real-time monitoring of the production process and energy conservation and emission reduction, reducing management problems caused by information asymmetry and conflicts of interest. Significant achievements have been made in improving enterprise ESG performance through synergistic governance, providing qualitative support for Hypothesis H5.

Research Significance and Innovations

1. Research Significance

(1) Theoretical Significance

This dissertation contributes to the literature by developing a more integrated explanation of how intelligent manufacturing may become part of an enterprise's broader sustainability capability. Existing studies on intelligent manufacturing have focused predominantly on outcomes such as productivity, innovation performance, operational upgrading, and firm value, whereas research on enterprise ESG performance has more often emphasized governance structure, ownership characteristics, financial conditions, and external institutional pressure. As a result, the theoretical linkage between production-side technological transformation and enterprise ESG performance has remained insufficiently developed.

The first theoretical contribution of this dissertation lies in extending the analytical scope of intelligent manufacturing research. Rather than treating intelligent manufacturing merely as a technical or production-related upgrade, the dissertation conceptualizes it as a composite organizational capability that reshapes resource allocation, information processing, stakeholder responsiveness, and governance coordination. This broader conceptualization makes intelligent manufacturing theoretically relevant to enterprise ESG performance and helps bridge the gap between technology-oriented and sustainability-oriented research.

The second contribution lies in providing a more structured explanation of the relationship between intelligent manufacturing and enterprise ESG performance. By integrating the Resource Based View, Stakeholder Theory, Information Asymmetry Theory, and Institutional Theory, the dissertation explains not only why intelligent manufacturing may improve ESG performance, but also through what processes and under what contextual conditions this relationship unfolds. In this respect, the dissertation moves beyond fragmented discussion of isolated channels and develops a more coherent theoretical basis for understanding the sustainability consequences of intelligent transformation.

The third contribution lies in generating theory-relevant evidence from the Chinese context. China provides an analytically important setting because intelligent manufacturing, green transition, and ESG institutionalization are unfolding simultaneously, while substantial regional, technological, and market heterogeneity remains. By examining this context, the dissertation extends the applicability of existing theories and contributes to a more context-sensitive understanding of how technological upgrading interacts with enterprise sustainability performance in an emerging economy.

(2) Practical and Policy Significance

At the practical level, the findings of this dissertation offer important implications for governments, enterprises, and capital markets.

First, from a governmental perspective, this dissertation provides micro-level empirical evidence to support the coordinated design of intelligent manufacturing and ESG related policies. The results suggest that intelligent manufacturing not only generates economic benefits by improving production efficiency, but also plays a positive role in enhancing enterprise ESG performance. These findings help policymakers better align intelligent manufacturing initiatives with objectives related to green and low-carbon transformation and the modernization of corporate governance.

Second, from a firm-level perspective, this dissertation offers guidance for firms to place greater emphasis on the systematic improvement of ESG performance when advancing intelligent manufacturing. The findings indicate that the ESG effects of intelligent manufacturing are not automatic, but instead depend on the coordinated improvement of information transparency, green innovation, financing conditions, and governance mechanisms. This provides valuable insights for firms in formulating intelligent transformation strategies and sustainable development pathways.

Finally, from a capital market perspective, this dissertation provides investors with a new analytical lens for identifying high-quality enterprises that combine strong intelligent manufacturing capabilities with long-term sustainability potential. By facilitating the allocation of long-term capital toward firms with both technological upgrading capacity and superior ESG performance, the dissertation contributes to improving the efficiency of capital market resource allocation.

2. Research Innovations

The originality of this dissertation lies not in treating intelligent manufacturing and enterprise ESG performance as separate areas of inquiry, but in showing how they can be analytically connected through a more precise research problem, a richer explanatory framework, and a more differentiated body of evidence. Relative to existing studies, the dissertation makes the following four contributions.

(1) Innovation in research problem development and analytical scope

The first innovation lies in the way the dissertation reformulates the research problem itself. Existing studies on intelligent manufacturing have mainly concentrated on productivity enhancement, innovation output, operational efficiency, and firm value, while research on enterprise ESG performance has tended to focus on governance structure, institutional pressure, ownership characteristics, and general digital transformation. As a result, the question of whether intelligent manufacturing can generate sustainability-related outcomes at the enterprise level has remained insufficiently specified. This dissertation advances the literature by moving beyond the conventional performance-oriented framing of intelligent manufacturing and recasting it as a firm-level transformation that may also shape environmental, social, and governance outcomes. In doing so, it shifts the discussion from whether intelligent manufacturing improves production performance to whether, how, and under what conditions it improves enterprise ESG performance. The innovation here is therefore not simply a change in perspective, but a clearer problem formulation that connects technological upgrading with sustainable corporate development within a unified research agenda.

(2) Innovation in explanatory framework and mechanism analysis

The second innovation lies in the construction of a multidimensional explanatory framework for analyzing the ESG consequences of intelligent manufacturing. Rather than relying on a single theoretical logic or treating mechanism variables as empirically convenient supplements, the dissertation organizes the analysis around a layered structure linking capability foundation, transmission processes, and contextual conditioning. Within this structure, the Resource Based View explains the capability basis of intelligent manufacturing; Stakeholder Theory and Information Asymmetry Theory explain how its effects are transmitted through informational, innovative, financial, and governance-related processes; and Institutional Theory explains why those effects vary across different organizational environments. This innovation is important because it moves the analysis beyond a reduced-form claim that intelligent manufacturing is simply "beneficial" for enterprise ESG performance. Instead, it explains how production-side technological transformation may be converted into sustainability-related outcomes through identifiable organizational processes and under identifiable contextual conditions. In this sense, the dissertation contributes not only by testing multiple mediating channels, but by embedding those channels in a coherent explanatory architecture that links technological upgrading, organizational change, and enterprise ESG performance in a more systematic way.

(3) Innovation in measurement logic and evidence design

The third innovation lies in the way the dissertation measures intelligent manufacturing and organizes empirical evidence. Instead of relying on a binary policy indicator or a purely disclosure-based proxy, this dissertation employs a PSFA based firm-level index that is more closely aligned with the concept of intelligent manufacturing as a continuous organizational capability. This measurement strategy allows the dissertation to capture substantive inter-firm and inter-temporal variation in the degree to which enterprises convert intelligent manufacturing-related inputs into effective operational outcomes. In addition, the dissertation adopts a layered evidence design in which the main relationship is examined through econometric analysis, then probed through mechanism testing, and further interpreted through qualitative case evidence from representative enterprises. The innovation here lies less in the use of individual econometric tools as such, and more in the construction of a capability-oriented and internally connected evidence structure that links measurement, identification, and mechanism interpretation in a coherent way.

(4) Innovation in findings refinement and contextual explanation

A further innovation lies in the dissertation's refinement of the substantive findings. Rather than presenting intelligent manufacturing as uniformly beneficial in a simple and linear sense, the study shows that its impact on enterprise ESG performance is both mechanism-dependent and context-specific.On the mechanism side, information transparency, green technological innovation, the alleviation of financing constraints, and synergistic governance all function as significant mediating channels. This indicates that intelligent manufacturing can improve enterprise ESG performance through better information conditions, stronger green innovation, improved financing support for sustainability-related investment, and more effective governance coordination. On the contextual side, the dissertation shows that the ESG effects of intelligent manufacturing vary systematically across regional environments, technological attributes, and listing-board segments. These findings move beyond a general claim that intelligent manufacturing is beneficial and instead offer a more differentiated explanation of the boundary conditions under which its sustainability consequences become stronger, weaker, or more uneven. In doing so, the dissertation contributes new evidence from China as a major emerging economy undergoing simultaneous intelligent transformation and ESG institutionalization.

In conclusion, these innovations define the distinct contribution of the dissertation. Its originality lies in developing a theoretically grounded, empirically connected, and context-sensitive explanation of how intelligent manufacturing may be translated into improved enterprise ESG performance. By doing so, the dissertation strengthens the connection between research on technological upgrading and research on sustainable corporate development, while also providing a more precise basis for future research in this area.

Research Scope and Limitations

1. Research Scope

This dissertation examines the impact of intelligent manufacturing on enterprise ESG performance. The scope of the research is defined in terms of the research object, time period, and research content, as detailed below.

First, regarding the research object, this dissertation focuses on Chinese A-share listed firms. In the empirical analysis, the final estimation sample is obtained after excluding firms in the financial and real estate industries, ST, *ST, or PT firms, and observations with missing or abnormal data. This treatment preserves the broader A-share setting of the study while improving sample comparability and ensuring that the key variables are interpreted within a relatively consistent production-oriented analytical framework. The firm-level intelligent manufacturing index used in this dissertation is intended to capture intelligent transformation in enterprise operations and organizational processes, rather than to classify enterprises by a narrow industry label. For this reason, the empirical analysis is not restricted to traditional manufacturing enterprises, although the final sample excludes industries for which the key variables are not directly comparable within the same analytical framework. Although common macroeconomic shocks are controlled through year fixed effects, this dissertation does not separately examine the moderating role of detailed province-year macroeconomic indicators. Future research may further explore how regional economic cycles, digital infrastructure, industrial policy intensity, and local fiscal capacity condition the relationship between intelligent manufacturing and enterprise ESG performance.

Second, regarding the time-period, this dissertation covers the years 2015-2023. On the one hand, the official release of *Made in China 2025* in 2015 marked the transition of intelligent manufacturing in China into a phase of systematic implementation. On the other hand, ESG ratings and related data have become increasingly available and standardized in recent years, providing the necessary conditions for long-term micro-level empirical analysis.

This period allows the study to comprehensively capture the dynamic evolution of enterprise ESG performance in the context of sustained intelligent manufacturing policy implementation.

Third, regarding the research content, this dissertation conducts a systematic firm-level analysis of the overall effect of intelligent manufacturing on enterprise ESG performance, with particular emphasis on the underlying transmission mechanisms, including information transparency, green innovation, financing constraints, and synergistic governance. In addition, by incorporating regional disparities, differences in enterprises' technological attributes, and the structure of China's multi-tier capital market, the dissertation further investigates the heterogeneous effects of intelligent manufacturing on enterprise ESG performance.

2. Research Limitations

Despite the rigorous research design and empirical analysis adopted in this dissertation, several limitations remain and warrant further investigation in future research.

First, in terms of variable measurement, both the intelligent manufacturing index and ESG ratings may be subject to measurement error. The level of intelligent manufacturing is difficult to fully capture using a single index, while ESG ratings may vary in indicator construction and weighting schemes. These measurement issues may affect the precision of the empirical estimates. Future studies may incorporate more granular firm-level data or multiple data sources to achieve more refined measurements of key variables.

Second, regarding causal identification, although this dissertation employs fixed effects models and a series of robustness checks to mitigate endogeneity concerns, it is still difficult to completely rule out potential reverse causality and omitted variable bias. Future research may further strengthen causal inference by exploiting more exogenous policy shocks or quasi-natural experimental designs.

Third, another limitation concerns the treatment of ownership structure. This dissertation controls for state ownership in the empirical model because ownership type is an important institutional characteristic in the Chinese context. State-owned enterprises may face stronger policy responsibilities, more stable access to financial resources, greater employment-stability obligations, and more formal governance requirements, while non-state-owned enterprises may be more directly shaped by market competition, financing pressure, and transformation flexibility. These differences may influence both the adoption of intelligent manufacturing and the conversion of intelligent transformation into ESG performance. However, the heterogeneity analysis in this dissertation is designed around the three dimensions that are most directly connected with the research hypotheses and analytical framework: regional development conditions, technological attributes, and listing-board characteristics. These dimensions respectively capture the institutional environment, technological absorptive capacity, and capital-market setting under which intelligent manufacturing may generate different ESG effects. Therefore, ownership structure is treated as a controlled institutional factor rather than as an independent heterogeneity dimension in the present empirical design. Future research may further develop an ownership-based analytical framework to examine how different types of enterprises convert intelligent manufacturing into ESG improvement. Such research may distinguish not only between state-owned and non-state-owned enterprises, but also among central SOEs, local SOEs, private enterprises, and mixed-ownership enterprises. This would help provide more targeted policy and managerial implications for enterprises with different ownership backgrounds.

Forth, concerning the research sample, this dissertation focuses exclusively on Chinese A-share listed firms, and the findings are therefore primarily applicable to the Chinese context. This sample provides relatively reliable and comparable data on financial characteristics, governance structure, intelligent manufacturing, and ESG performance, which is necessary for constructing a consistent firm-level panel dataset. However, the findings should not be interpreted as representing all Chinese enterprises. Listed firms usually have larger organizational scale, more formalized governance structures, stronger disclosure capacity, and better access to external finance than non-listed small and medium-sized enterprises. Therefore, the conclusions of this dissertation are most directly applicable to the listed corporate sector. For SMEs, the basic logic that intelligent manufacturing may support ESG improvement remains relevant, but the strength and pathway of this effect may depend more heavily on digital infrastructure, financing availability, managerial capability, supply-chain linkages, and simplified ESG disclosure capacity. Future research may further examine whether the mechanisms identified in this dissertation remain valid for non-listed SMEs when more comparable data become available.

Finally, with respect to mechanism analysis, although this dissertation explores multiple transmission channels, including information transparency, green innovation, financing constraints, and synergistic governance, the process of corporate sustainable development is inherently complex, and other potential mechanisms may also play a role. Future research may extend the analysis to additional mechanisms to further deepen the understanding of the relationship between intelligent manufacturing and enterprise ESG performance.

CHAPTER 1. THEORETICAL AND LITERATURE REVIEW

1.1 Theoretical Foundations

1.1.1 Resource Based View

The Resource Based View (RBV) provides a fundamental theoretical basis and an important theoretical foundation for understanding how intelligent manufacturing influences enterprise ESG performance. Penrose (1959) first conceptualized the enterprise as a bundle of productive resources, emphasizing that firm growth and performance depend on how resources are deployed rather than merely on industry structure. Building on this idea, Wernerfelt (1984) formally proposed the Resource Based View, which was later further developed and popularized by Barney (1991). RBV argues that enterprises achieve competitive advantage through the possession and effective utilization of heterogeneous and imperfectly mobile resources.

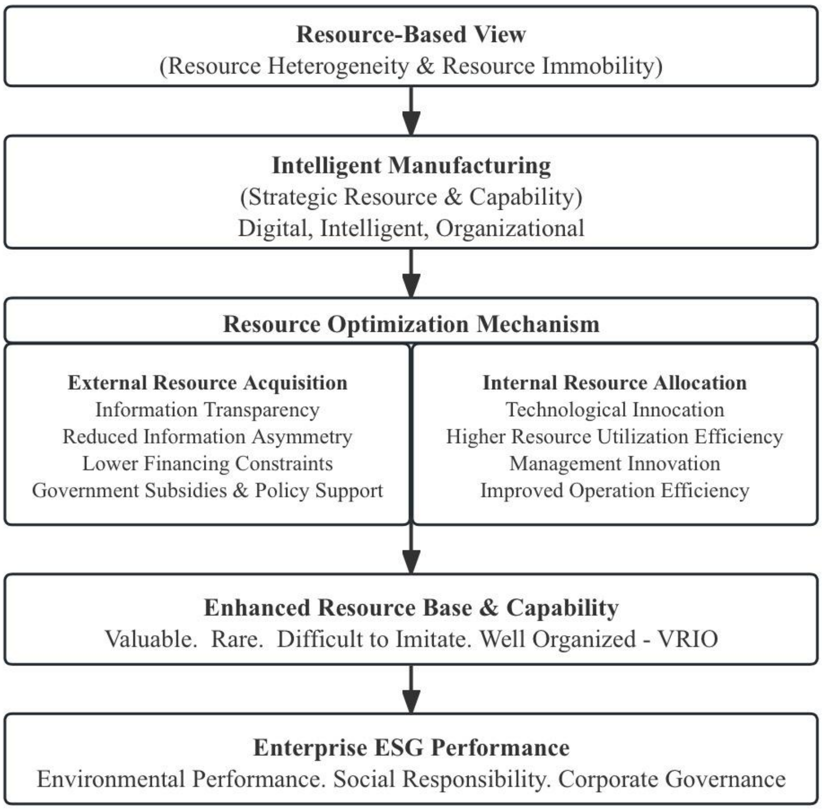
According to RBV, enterprise resources can be broadly classified into tangible resources (such as physical assets and financial capital) and intangible resources (such as technological capabilities, organizational processes, and managerial expertise). Two key assumptions underpin the RBV framework: resource heterogeneity and resource immobility. However, possessing heterogeneous and immobile resources alone is insufficient to sustain competitive advantage. Barney (1991) further proposed the VRIN framework, suggesting that only resources that are valuable, rare, difficult to imitate, and non-substitutable can generate sustained competitive advantage. This framework was later refined by Rothaermel (2013) into the VRIO framework, which emphasizes not only the intrinsic characteristics of resources but also enterprises' organizational capabilities to effectively capture value from these resources.

From the perspective of ESG activities, RBV offers a compelling explanation for why resource availability and allocation are critical constraints. ESG investments are typically characterized by high capital intensity, long investment horizons, and substantial uncertainty in returns. Many ESG projects face severe financing constraints and difficulties in obtaining external funding, leading to a pronounced resource bottleneck. Moreover, due to the long-term and uncertain nature of ESG returns, enterprises with limited internal resources may prioritize short-term projects with more predictable financial outcomes, further crowding out resources allocated to ESG related activities. According to RBV, a strong and flexible resource base is therefore a fundamental prerequisite for enterprises to engage in and sustain ESG initiatives.

Intelligent manufacturing plays a crucial role in alleviating ESG related resource constraints through both external resource acquisition and internal resource allocation mechanisms. From the perspective of external resource acquisition, intelligent manufacturing enhances information transparency by improving data collection, processing, and disclosure capabilities. Higher transparency reduces information asymmetry between firms and external stakeholders, strengthens enterprises' perceived competitiveness, and improves credibility in capital markets. As a result, enterprises implementing intelligent manufacturing are more likely to alleviate financing constraints, reduce financing costs, and expand access to external funding. In addition, as intelligent manufacturing represents a core technology in the new wave of industrial transformation and is strongly supported by government policies, enterprises engaged in intelligent manufacturing are more likely to receive external resource support such as government subsidies, tax incentives, and preferential financing.

From the perspective of internal resource allocation, intelligent manufacturing significantly enhances enterprises' ability to utilize and manage existing resources more efficiently. First, intelligent manufacturing promotes technological innovation, which improves resource utilization efficiency, capacity utilization, operational efficiency, and total factor productivity. These improvements allow enterprises to generate greater output and value from a given resource base, thereby freeing up internal resources that can be reallocated to ESG activities. Second, intelligent manufacturing facilitates management innovation by enabling enterprises to establish intelligent management systems, optimize organizational processes, and improve internal coordination. Enhanced managerial capabilities strengthen enterprises' ability to allocate resources strategically and reduce internal inefficiencies.

Figure 1.5 Resource Based View Framework of Intelligent Manufacturing and Enterprise ESG Performance



Source: developed by the author

Figure 1.5 illustrates the theoretical framework of this dissertation based on the Resource Based View. The figure illustrates how intelligent manufacturing, as a strategic resource and organizational capability, influences enterprise ESG performance through resource optimization mechanisms. Specifically, intelligent manufacturing enhances both external resource acquisition and internal resource allocation efficiency, which together strengthen enterprises' resource bases and support sustained ESG engagement. This framework serves as a conceptual guide for the hypothesis development and empirical analysis that follow.

In sum, intelligent manufacturing contributes to the development of valuable, rare, and difficult-to-imitate capabilities by optimizing both external resource acquisition and internal resource allocation. Through these resource optimization effects, intelligent manufacturing strengthens enterprises' resource bases and organizational capabilities, thereby providing essential support for sustained ESG engagement. Consistent with the Resource-Based View, intelligent manufacturing can thus be regarded as a strategic resource that enhances enterprises' ability to improve ESG performance by overcoming resource constraints and improving resource deployment efficiency.

1.1.2 Stakeholder Theory

Stakeholder Theory provides a comprehensive theoretical foundation for explaining how intelligent manufacturing affects enterprise ESG performance through multiple transmission mechanisms. Originating from management and organizational theory, this perspective was formally articulated by Freeman (1984), who argued that enterprises are embedded in a network of relationships with multiple stakeholders rather than operating solely for the benefit of shareholders. Freeman classified stakeholders into internal stakeholders, such as employees, managers, and shareholders, and external stakeholders, including customers, suppliers, governments, communities, and the natural environment. Subsequently, Carroll (1996) further expanded this definition, conceptualizing stakeholders as any individual or group that can affect or be affected by an enterprise's operations.

According to Stakeholder Theory, enterprises face multidimensional constraints and expectations arising from diverse stakeholder groups. Corporate decision-making should therefore incorporate not only economic objectives but also social and environmental responsibilities. Enterprises that effectively respond to stakeholder expectations are more likely to gain legitimacy, trust, and long-term support, which are essential for sustainable development. In this sense, ESG performance can be viewed as a comprehensive outcome reflecting how well firms balance and satisfy the interests of multiple stakeholders.

The application of intelligent manufacturing technologies fundamentally reshapes the way enterprises interact with stakeholders. By integrating digital technologies, intelligent equipment, and data platforms into production and management processes, intelligent manufacturing enables enterprises to optimize operational efficiency while simultaneously reducing environmental and social costs. These improvements lower the marginal cost of fulfilling stakeholder responsibilities, thereby enhancing enterprises' incentives and capacity to engage in ESG related activities.

More importantly, intelligent manufacturing promotes a transparent and data-driven governance environment, which strengthens information flows between enterprises and both internal and external stakeholders. Enhanced information transparency allows external stakeholders, such as investors, regulators, and the public, to better understand enterprises' operational practices, environmental performance, and governance structures. This increased transparency constrains opportunistic behavior by managers or controlling shareholders who might otherwise exploit information asymmetries for private benefit, thereby improving corporate governance quality.

At the same time, intelligent manufacturing enables enterprises to allows enterprises to collect, process, and analyze stakeholder-related information in real time. This capability helps enterprises more effectively identify and respond to the heterogeneous demands of different stakeholder groups, such as environmental protection requirements from regulators, product quality expectations from customers, workplace safety concerns from employees, and sustainability preferences from investors. By facilitating timely coordination and interest balancing among stakeholders, intelligent manufacturing supports a shift from fragmented stakeholder management toward more integrated and synergistic governance.

From the perspective of Stakeholder Theory, ESG performance can be understood as a comprehensive reflection of how effectively an enterprise fulfills its responsibilities to different stakeholders. The environmental dimension reflects the enterprise's responsibility to regulators, communities, and society in relation to ecological protection and sustainable resource use. The social dimension concerns the enterprise's treatment of employees, consumers, suppliers, and communities. The governance dimension reflects whether the enterprise has established transparent, accountable, and participatory decision-making arrangements that protect the interests of investors and other relevant stakeholders. Therefore, any organizational transformation that improves an enterprise's capability to coordinate stakeholder relationships is likely to promote ESG performance.

Intelligent manufacturing represents such a transformation. Through the integration of digital technologies, intelligent equipment, industrial internet platforms, and data-driven management systems, intelligent manufacturing reshapes how enterprises interact with stakeholders, allocate resources, disclose information, and organize production and governance processes. Under Stakeholder Theory, the ESG effects of intelligent manufacturing can be explained through four specific mechanisms.

First, intelligent manufacturing can enhance information transparency, thereby improving stakeholder trust and external monitoring. Digitalized production systems, real-time data collection, and traceable operational processes enable enterprises to disclose more timely, accurate, and credible information regarding production activities, environmental performance, energy use, product quality, and governance practices. For external stakeholders such as investors, regulators, customers, and communities, improved transparency reduces uncertainty and information asymmetry, strengthens oversight, and increases the credibility of corporate ESG commitments. For internal stakeholders, greater transparency also helps align managerial actions with broader organizational and stakeholder interests. Therefore, from a stakeholder perspective, information transparency is a key mechanism through which intelligent manufacturing improves ESG performance.

Second, intelligent manufacturing can promote green innovation, thereby strengthening the enterprise's capacity to respond to stakeholders' environmental and social expectations. Stakeholder Theory emphasizes that enterprises face growing demands not only for economic performance but also for cleaner production, safer products, lower emissions, and more sustainable development pathways. Intelligent manufacturing supports these expectations by enabling more precise process control, more efficient resource utilization, better environmental monitoring, and stronger integration of digital technologies with green production systems. These capabilities create favorable conditions for green product innovation, green process innovation, and cleaner technological upgrading. As a result, intelligent manufacturing helps enterprises transform stakeholder pressure for sustainability into concrete innovation outcomes, which in turn improve ESG performance.

Third, intelligent manufacturing may alleviate financing constraints, thereby enhancing the enterprise's ability to sustain stakeholder-oriented ESG investment. From the viewpoint of Stakeholder Theory, access to financial resources is not only an economic issue but also a relational one. Creditors, investors, and capital market participants are important stakeholders whose support depends heavily on the enterprise's credibility, transparency, risk profile, and long-term strategic orientation. Intelligent manufacturing can improve operational efficiency, reduce production uncertainty, and strengthen information disclosure, thereby increasing stakeholder confidence in the enterprise's future prospects. This may lower financing costs, improve access to external capital, and ease financing constraints. Once financing conditions improve, enterprises are better able to undertake long-term expenditures related to environmental protection, employee welfare, social responsibility programs, and governance improvement. Accordingly, financing constraints constitute another important mechanism linking intelligent manufacturing and ESG performance under the stakeholder framework.

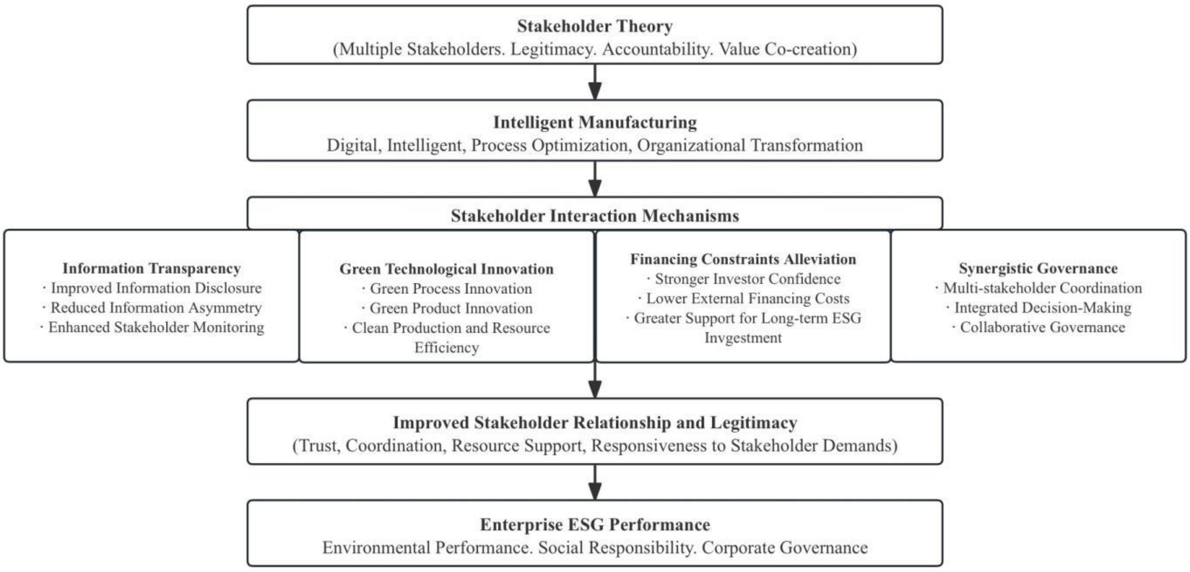
Fourth, intelligent manufacturing can strengthen synergistic governance, which directly reflects the stakeholder-oriented logic of coordinated value creation. Stakeholder Theory does not merely stress that enterprises should acknowledge multiple stakeholders; it also emphasizes that enterprises must build governance arrangements capable of balancing different interests and facilitating cooperation among relevant actors. Intelligent manufacturing promotes such coordination by connecting departments, supply chain partners, regulators, and other stakeholders through shared data systems, integrated platforms, and more responsive organizational structures. These changes improve communication efficiency, support joint problem-solving, and reduce coordination failures in areas such as environmental management, employee protection, quality control, and compliance. Consequently, intelligent manufacturing enhances the enterprise’s ability to implement ESG related decisions through collaborative and cross-functional governance processes. In this sense, synergistic governance is not only a mechanism supported by Stakeholder Theory, but also one of its most direct organizational manifestations.

Taken together, Stakeholder Theory suggests that intelligent manufacturing improves enterprise ESG performance because it enhances the enterprise’s capability to manage stakeholder relationships in a more transparent, innovative, financially sustainable, and coordinated manner. Specifically, intelligent manufacturing strengthens stakeholder trust through better information transparency, responds to sustainability demands through green technological innovation, improves resource support for ESG activities by alleviating financing constraints, and enhances collective action through synergistic governance. These four mechanisms jointly explain how intelligent manufacturing helps enterprises better satisfy stakeholder expectations and achieve superior ESG outcomes.

To clarify the governance dimension more explicitly, intelligent manufacturing is understood in this dissertation as affecting governance structure not only through stronger monitoring or disclosure, but also through the reorganization of how ESG related decisions are coordinated and executed. In conventional production settings, environmental management, quality control, supply-chain coordination, compliance, and stakeholder communication are often dispersed across separate functions and disconnected information systems. Intelligent manufacturing changes this condition by creating shared data environments, real-time visibility, process traceability, and integrated operational platforms. These changes reduce organizational fragmentation, strengthen cross-functional coordination, and improve the consistency with which ESG related rules and objectives are implemented. On this basis, synergistic governance is treated not merely as a governance outcome, but as the more specific organizational mechanism through which intelligent manufacturing is translated into more coherent governance execution and, ultimately, better enterprise ESG performance.

Therefore, Stakeholder Theory provides an integrated theoretical basis for the four mechanism hypotheses proposed in this dissertation. It not only explains why intelligent manufacturing may improve ESG performance in general, but also clarifies the specific stakeholder-related channels through which this effect is realized.

Figure 1.6 Stakeholder Theory Framework of Intelligent Manufacturing and Enterprise ESG Performance



Source: developed by the author

Figure 1.6 illustrates the theoretical framework of this dissertation based on Stakeholder Theory. The figure shows how intelligent manufacturing, as a multidimensional organizational transformation, influences enterprise ESG performance through stakeholder interaction mechanisms. Specifically, intelligent manufacturing strengthens enterprises' ability to respond to diverse stakeholder demands by improving information transparency, promoting green technological innovation, alleviating financing constraints, and enhancing synergistic governance. In the governance-related pathway, intelligent manufacturing is theorized to improve ESG performance not only by strengthening monitoring and stakeholder coordination, but also by reducing organizational fragmentation through shared data, process visibility, and cross-functional governance integration. Through these mechanisms, enterprises can improve stakeholder relationship management, reinforce organizational legitimacy, and better fulfill their environmental, social, and governance responsibilities. This framework provides the stakeholder-based theoretical foundation for the mechanism hypotheses and subsequent empirical analysis in this dissertation.

In summary, Stakeholder Theory provides a unified analytical framework for understanding how intelligent manufacturing affects enterprise ESG performance through four interrelated mechanisms. By improving information transparency, intelligent manufacturing enhances stakeholder monitoring and legitimacy. By promoting green innovation, it helps enterprises respond to growing environmental and social expectations. By alleviating financing constraints, it strengthens the resource base required for sustained ESG investment. By reinforcing synergistic governance, it improves coordination and collaborative decision-making among multiple stakeholders. Accordingly, Stakeholder Theory not only supports the overall positive relationship between intelligent manufacturing and enterprise ESG performance, but also offers direct theoretical justification for the four mechanism hypotheses proposed in this dissertation.

1.1.3 Information Asymmetry Theory

Information Asymmetry Theory provides an important theoretical foundation for explaining how intelligent manufacturing influences enterprise ESG performance through multiple intermediary channels. Information asymmetry theory, a fundamental concept in economics, refers to the unequal distribution of information among market participants in the process of acquiring and interpreting market information, whereby some participants possess more or better information than others (Akerlof, 1978; Spence, 1973; Stiglitz, 1989). In real-world markets, information asymmetry is pervasive, as information acquisition is costly and market participants are forced to make decisions under conditions of incomplete information. A common manifestation of information asymmetry is that sellers possess superior knowledge about their products or operating conditions compared to buyers, which can lead to market failure and distortions in the allocation of social resources.

Information asymmetry gives rise to classic principal-agent problems, including adverse selection and moral hazard (Akerlof, 1978; Spence, 1973; Spence, 1974). Adverse selection occurs ex ante when information disadvantages lead to inefficient market participation, while moral hazard represents ex post opportunistic behavior in which one party fails to fulfill its responsibilities after a transaction has taken place, thereby harming the interests of the principal. In the corporate context, moral hazard may manifest when managers, driven by private incentives, engage in opportunistic behavior, such as excessive or symbolic investment in corporate social responsibility or ESG activities, that does not align with shareholders’ long-term interests.

According to signaling theory proposed by Spence (1973), in environments characterized by information asymmetry, informed parties may transmit signals to uninformed parties to convey favorable information about their quality or intentions. However, not all signals are credible, and ineffective or low-quality disclosure may fail to alleviate information asymmetry. Therefore, information asymmetry theory emphasizes that strengthening information disclosure, regulating disclosure practices, and enhancing information transparency are essential mechanisms for mitigating adverse selection and moral hazard (Grossman and Stiglitz, 1980).

In recent years, enterprise ESG information has increasingly been regarded as a critical channel through which enterprises communicate their sustainability strategies, risk management practices, and long-term value creation potential to capital markets. ESG disclosure conveys enterprises' commitments and intentions to proactively manage environmental, social, and governance risks, thereby reducing investors' exposure to ESG related uncertainty arising from information asymmetry (Khan et al., 2016; Amel-Zadeh and Serafeim, 2018; Gerwanski et al., 2019). As such, ESG information serves not merely as non-financial disclosure, but as economically relevant information that complements traditional financial reporting.

From the perspective of information asymmetry theory, asymmetric information between firms and external stakeholders constitutes an important source of governance inefficiency and capital misallocation. Intelligent manufacturing plays a crucial role in alleviating information asymmetry by transforming enterprises' information generation and disclosure processes. Through the adoption of digital information systems, intelligent monitoring equipment, and data platforms, intelligent manufacturing significantly enhances enterprises' capabilities in information collection, processing, and transmission. These improvements increase the accuracy, timeliness, and consistency of corporate information disclosure, thereby improving overall information transparency.

Enhanced information transparency reduces information asymmetry between enterprises and external stakeholders, including investors and regulators, strengthens external governance constraints, and mitigates opportunistic behavior by managers or controlling shareholders. As a result, enterprises are incentivized to make more standardized and responsible decisions in environmental management, social responsibility fulfillment, and corporate governance practices. In this sense, intelligent manufacturing contributes to improved ESG performance not only through operational efficiency gains, but also by serving as an effective informational governance mechanism.

This perspective is highly relevant to ESG related issues. ESG performance involves not only observable outcomes, but also a large number of internal processes, strategic choices, and managerial commitments that are difficult for external stakeholders to assess directly. For example, investors may find it difficult to determine whether an enterprise's environmental initiatives are substantive or merely symbolic; creditors may be unable to fully observe the long-term risk implications of corporate transformation; and regulators or the public may not immediately detect whether an enterprise's governance practices genuinely support sustainability objectives. As a result, information asymmetry may weaken stakeholder trust, raise financing costs, distort incentives, and reduce the effectiveness of external monitoring. Under such conditions, enterprises may under-invest in long-term ESG activities or adopt opportunistic strategies that damage sustainable performance.

Against this background, intelligent manufacturing can be understood as an organizational and technological transformation that significantly reduces information asymmetry. Through the adoption of digital technologies, intelligent equipment, industrial internet platforms, and integrated data systems, firms are able to generate, transmit, and process production and management information in a more accurate, timely, and traceable manner. Operational processes become more visible, resource use becomes more measurable, and managerial actions become easier to monitor. Consequently, intelligent manufacturing strengthens the information environment surrounding the enterprise and changes how both internal and external stakeholders perceive corporate quality, risk, and commitment. From the perspective of Information Asymmetry Theory, this improved information environment provides theoretical support for the four mechanism hypotheses in this dissertation.

First, intelligent manufacturing can improve information transparency, which is the most direct mechanism implied by Information Asymmetry Theory. The theory suggests that when enterprises disclose more reliable and timely information, uncertainty faced by external stakeholders declines, and both adverse selection and moral hazard can be mitigated. Intelligent manufacturing contributes to this process by enabling real-time data collection, integrated information sharing, and more standardized reporting systems. These improvements enhance the quality of information disclosure regarding operational efficiency, environmental performance, energy consumption, product quality, and internal governance. As information transparency increases, investors, regulators, customers, and other stakeholders are better able to evaluate corporate behavior and monitor ESG related commitments. Therefore, Information Asymmetry Theory directly supports the hypothesis that intelligent manufacturing promotes ESG performance by enhancing information transparency.

Second, Information Asymmetry Theory also helps explain how intelligent manufacturing may foster green innovation. Green innovation is typically characterized by long investment cycles, high uncertainty, and strong information opacity. External stakeholders often find it difficult to observe the real quality, progress, and expected returns of green technological activities, which may reduce their willingness to support such investments. Internal decision-makers may likewise hesitate to commit resources when future benefits are uncertain and difficult to communicate. Intelligent manufacturing reduces these informational barriers by improving data availability, process monitoring, and the enterprise's ability to identify inefficiencies, emissions sources, and opportunities for cleaner production. More importantly, better information systems allow enterprises to evaluate innovation projects more accurately, communicate their innovation potential more credibly, and reduce uncertainty surrounding green transformation. In this sense, lower information asymmetry facilitates the initiation, implementation, and diffusion of green innovation, thereby providing a theoretical basis for the green innovation mechanism hypothesis.

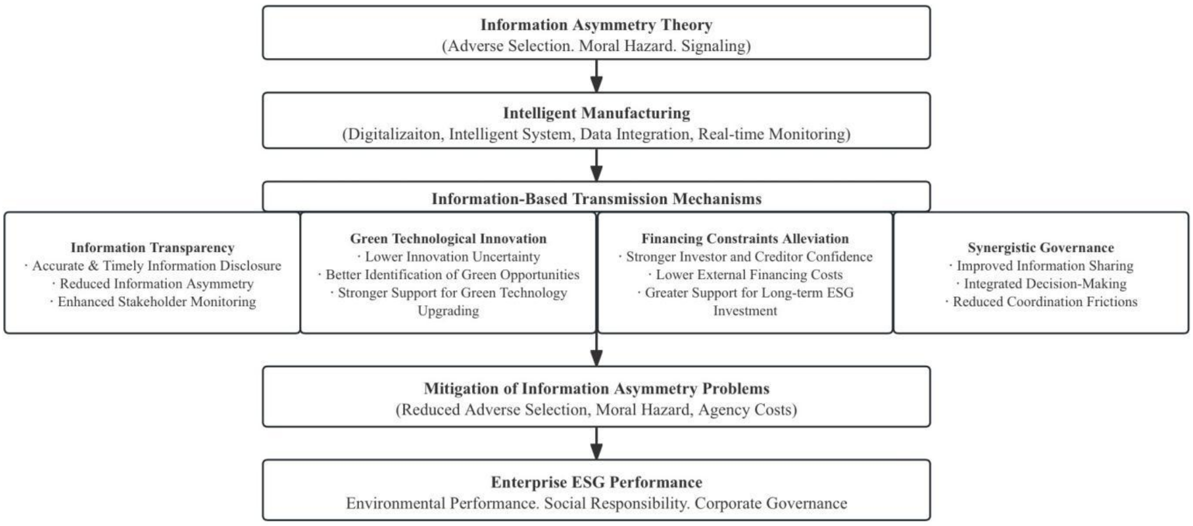
Third, Information Asymmetry Theory provides a strong explanation for the mechanism of financing constraints. One of the central propositions of the theory is that capital providers face difficulty distinguishing between high-quality and low-quality borrowers when information is incomplete. This often leads to credit rationing, higher external financing costs, and stronger financing constraints, especially for enterprises undertaking long-term, uncertain, and intangible investments. ESG related activities and intelligent transformation share many of these characteristics. When stakeholders cannot adequately assess an enterprise's real operational capacity or future prospects, they may demand higher risk premiums or reduce their willingness to provide funding. Intelligent manufacturing alleviates this problem by improving operational visibility, strengthening disclosure quality, and generating more credible signals about the enterprise's productivity, management capability, and development potential. As information asymmetry declines, external investors and creditors can evaluate enterprises more accurately, which may increase financing availability and reduce financing costs. This, in turn, provides enterprises with greater financial capacity to invest in environmental protection, employee welfare, governance improvement, and other ESG related activities. Accordingly, Information Asymmetry Theory clearly supports the financing constraints mechanism proposed in this dissertation.

Fourth, Information Asymmetry Theory can also support the mechanism of synergistic governance. Governance failures often arise not only from conflicts of interest, but also from insufficient or fragmented information among organizational participants. When departments, managers, employees, suppliers, investors, and regulators do not share timely and accurate information, coordination costs rise and collective decision-making becomes less effective. Under such conditions, ESG related governance may become fragmented, reactive, or symbolic. Intelligent manufacturing helps address this problem by establishing interconnected data systems, improving information sharing across organizational units, and creating more transparent interfaces between enterprises and relevant stakeholders. Better information flow reduces misunderstandings, lowers coordination frictions, and strengthens the basis for integrated decision-making. In this way, lower information asymmetry enhances the enterprise's ability to coordinate internal and external stakeholders around ESG goals, thereby supporting more effective synergistic governance. Therefore, from the perspective of Information Asymmetry Theory, synergistic governance is not only a governance outcome, but also a consequence of improved information conditions generated by intelligent manufacturing.

Taken together, Information Asymmetry Theory suggests that intelligent manufacturing affects enterprise ESG performance by improving the enterprise's overall information environment and reducing uncertainty across stakeholder relationships. The four mechanism channels are therefore logically connected rather than completely independent. Among them, information transparency and financing constraints form an information-resource conversion logic. Improved information transparency enhances the credibility of intelligent transformation and ESG commitment by strengthening data traceability, process visibility, disclosure quality, and stakeholder monitoring. This reduces uncertainty for investors and creditors and may improve firms' external credit recognition. However, whether such informational improvement can be translated into substantive ESG outcomes depends on the availability of financial resources. If financing constraints remain severe, enterprises may still be unable to sustain investment in environmental protection, employee responsibility, green innovation, and governance improvement. In this sense, information transparency represents the informational basis for external trust, while financing constraints represent the resource condition for sustained ESG investment.

Therefore, Information Asymmetry Theory provides a coherent and powerful explanation for the four mechanism hypotheses proposed in this dissertation. It not only clarifies why intelligent manufacturing may improve enterprise ESG performance in general, but also identifies the specific information-based pathways through which this effect can be realized.

Figure 1.7 Information Asymmetry Theory Framework of Intelligent Manufacturing and Enterprise ESG Performance



Source: developed by the author

Figure 1.7 illustrates the theoretical framework of this dissertation based on Information Asymmetry Theory. The figure demonstrates how intelligent manufacturing, through digitalization, intelligent systems, data integration, and real-time monitoring, influences enterprise ESG performance by mitigating information asymmetry problems. Specifically, intelligent manufacturing improves information transparency, facilitates green technological innovation, alleviates financing constraints, and strengthens synergistic governance by enhancing information disclosure, reducing uncertainty, and improving coordination efficiency. These effects help reduce adverse selection, moral hazard, and agency costs, thereby creating more favorable conditions for enterprises to improve their ESG performance. This framework provides an information-based explanation for the mechanism hypotheses and empirical analysis developed in this dissertation.

In summary, Information Asymmetry Theory offers an integrated framework for understanding how intelligent manufacturing improves enterprise ESG performance through four mechanism channels. By reducing information asymmetry, intelligent manufacturing enhances information transparency, promotes green innovation, alleviates financing constraints, and strengthens synergistic governance. These effects improve stakeholder monitoring, increase the credibility of corporate signals, facilitate long-term resource support, and promote more coordinated ESG related decision-making. Accordingly, Information Asymmetry Theory not only supports the overall positive relationship between intelligent manufacturing and ESG performance, but also provides direct theoretical justification for the four mechanism hypotheses examined in this dissertation.

1.1.4 Institutional Theory

Institutional Theory provides an important complementary perspective for understanding how enterprises' strategic behaviors are shaped by the broader institutional environment. Originating from sociology and organizational theory, institutional theory emphasizes that enterprises are embedded in social, political, and regulatory contexts and are subject to formal and informal institutional pressures (Meyer and Rowan, 1977; DiMaggio and Powell, 1983). Rather than being driven solely by efficiency considerations, enterprises often adopt organizational practices and strategic choices in response to institutional expectations in order to obtain legitimacy, stability, and access to critical resources.

A core proposition of institutional theory is that organizational behavior is influenced by three types of institutional pressures: coercive, normative, and mimetic pressures (DiMaggio and Powell, 1983). Coercive pressures arise from formal regulations, laws, and government policies; normative pressures stem from professional norms, social values, and stakeholder expectations; and mimetic pressures reflect enterprises' tendencies to imitate leading or successful peers under conditions of uncertainty. Together, these pressures shape enterprises' strategic responses and contribute to organizational convergence within specific institutional environments.

In the context of sustainable development, institutional theory has been widely applied to explain corporate engagement in environmental protection, social responsibility, and ESG related activities. Governments and regulators increasingly impose environmental standards, disclosure requirements, and sustainability-related regulations, creating coercive pressures for firms to improve ESG performance. At the same time, growing societal awareness of sustainability issues and the diffusion of ESG norms generate normative pressures that encourage enterprises to adopt responsible practices. Moreover, as ESG oriented strategies and intelligent manufacturing practices become more prevalent among leading enterprises, mimetic pressures may further accelerate their diffusion across industries.

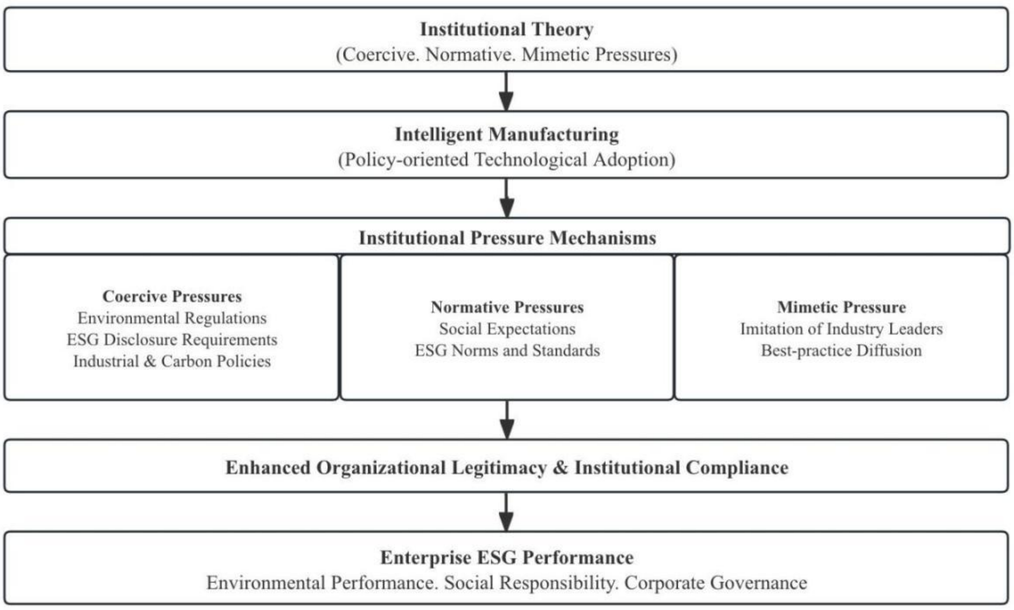
Institutional theory is particularly relevant in the Chinese context, where economic development and corporate behavior are strongly influenced by policy orientation and government intervention. Since the introduction of *Made in China 2025* and subsequent intelligent manufacturing development plans, the Chinese government has explicitly promoted intelligent manufacturing as a strategic tool for industrial upgrading, green transformation, and high-quality development. Simultaneously, the advancement of the "dual-carbon" goals and the strengthening of ESG related regulations have increased institutional pressure on enterprises to improve their environmental, social, and governance performance.

Under such a policy-driven institutional environment, enterprises' adoption of intelligent manufacturing is not only an efficiency-driven choice but also a strategic response to institutional expectations and regulatory requirements.

From an institutional perspective, intelligent manufacturing can enhance enterprise ESG performance by helping enterprises better comply with regulatory standards, align with societal norms, and signal legitimacy to external stakeholders. Intelligent manufacturing facilitates standardized production processes, real-time environmental monitoring, and traceable information disclosure, which enable enterprises to more effectively meet regulatory and disclosure requirements. By conforming to institutional expectations regarding sustainability and governance, enterprises can reduce regulatory risks, improve legitimacy, and secure continued access to policy support and market opportunities.

Furthermore, institutional heterogeneity across regions and capital markets may lead to differential impacts of intelligent manufacturing on enterprise ESG performance. Regions with stronger regulatory enforcement, more developed market institutions, and higher levels of policy support may exhibit stronger institutional pressures, amplifying the ESG effects of intelligent manufacturing. Similarly, enterprises operating in more mature capital markets with stricter disclosure requirements and greater investor scrutiny may respond more strongly to institutional pressures related to ESG performance. In this sense, institutional theory provides an important explanation for the heterogeneous effects of intelligent manufacturing observed across regions, firm types, and listing boards.

Figure 1.8 Institutional Theory Framework of Intelligent Manufacturing and Enterprise ESG Performance



Source: developed by the author

Figure 1.8 presents the institutional theory based conceptual framework of this dissertation. The figure illustrates how intelligent manufacturing operates under coercive, normative, and mimetic institutional pressures. By enhancing organizational legitimacy and institutional compliance, intelligent manufacturing contributes to improved enterprise ESG performance.

In summary, institutional theory complements firm-level theories by highlighting the role of external regulatory, normative, and mimetic pressures in shaping corporate behavior. In a policy-driven emerging economy such as China, institutional forces play a critical role in influencing enterprises' adoption of intelligent manufacturing and their subsequent ESG performance. This perspective enriches the theoretical framework of this dissertation by situating firm-level mechanisms within a broader institutional context and provides a theoretical basis for understanding cross-sectional heterogeneity in the effects of intelligent manufacturing on enterprise ESG performance.

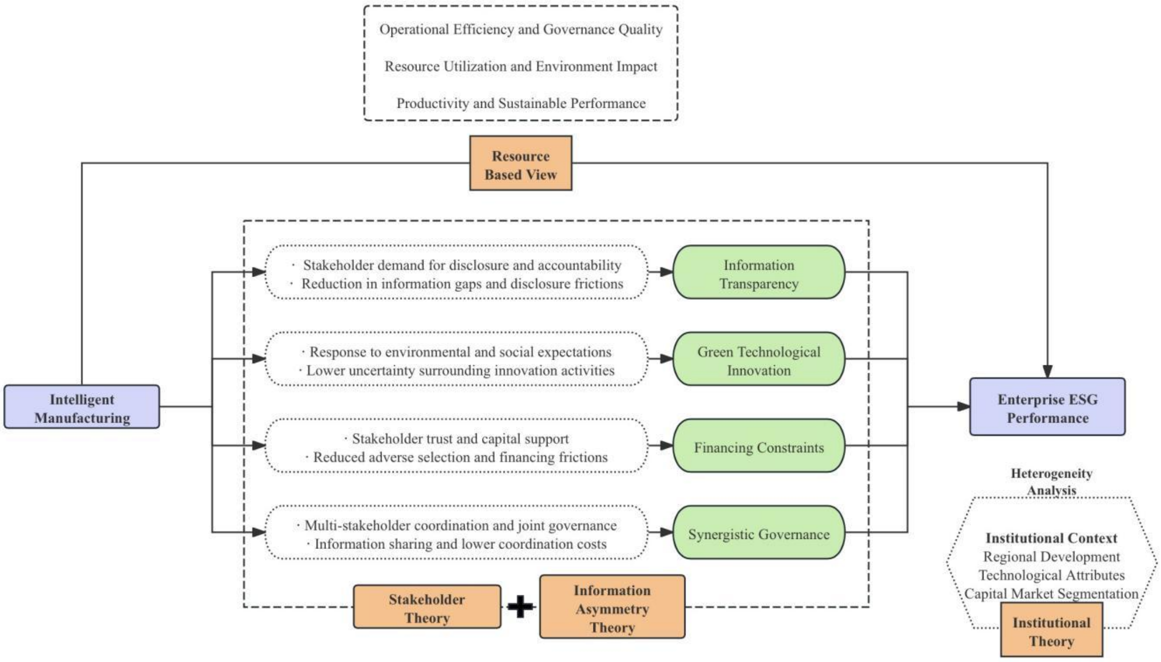
1.1.5 Summary of Theoretical Foundations

The preceding discussion shows that the relationship between intelligent manufacturing and enterprise ESG performance requires a multi-theoretical explanation rather than a single-theory account. In this dissertation, the theoretical foundations are organized around three interconnected analytical tasks: explaining the internal capability basis of intelligent manufacturing, clarifying the organizational processes through which it affects enterprise ESG performance, and identifying the contextual conditions under which such effects become stronger or weaker.

Within this structure, the Resource Based View explains the capability foundation of the relationship by showing how intelligent manufacturing strengthens the internal basis for sustained ESG improvement. Stakeholder Theory and Information Asymmetry Theory explain the principal transmission processes through which intelligent manufacturing may affect enterprise ESG performance, especially through stakeholder responsiveness, information transparency, and governance-related improvements. Institutional Theory adds the contextual dimension by clarifying why the ESG consequences of intelligent manufacturing may vary across regional, technological, and capital-market environments.

Taken together, these perspectives form a layered explanatory framework in which capability formation, organizational transmission, and contextual conditioning are analytically connected. On this basis, the theoretical foundations developed in this chapter provide the conceptual support for the hypotheses, empirical models, mechanism analyses, and heterogeneity tests presented in the subsequent chapters.

Figure 1.9 Overall Theoretical Framework of Intelligent Manufacturing and Enterprise ESG Performance



Source: developed by the author

Figure 1.9 illustrates the integrated theoretical framework of this dissertation. The figure shows how intelligent manufacturing influences enterprise ESG performance through multiple theoretical perspectives and mechanism channels. Specifically, the Resource Based View explains the direct effect of intelligent manufacturing on ESG performance by emphasizing its role in improving operational efficiency, resource utilization, governance quality, and sustainable performance. Stakeholder Theory and Information Asymmetry Theory jointly explain the indirect effect through four mediating mechanisms: information transparency, green technological innovation, financing constraints, and synergistic governance. In addition, Institutional Theory provides the basis for the heterogeneity analysis by highlighting how this relationship may vary across different institutional contexts, including regional development, technological attributes, and capital market segmentation. This framework serves as the overall conceptual guide for the hypothesis development and empirical analysis presented in this dissertation.

1.2 Intelligent Manufacturing Related Literature Review

1.2.1 Evolution of Manufacturing Paradigms and the Conceptualization of Intelligent Manufacturing

Manufacturing systems have undergone a long-term evolutionary process, progressing from traditional manufacturing to smart manufacturing and further toward intelligent manufacturing. This evolution reflects not only rising levels of automation, digitalization, and connectivity, but also a deeper transformation in production logic, managerial coordination, and the role of data in industrial decision-making. As manufacturing paradigms have evolved, the concept of intelligent manufacturing has gradually moved beyond a narrow engineering interpretation and become a broader analytical category used to describe the integration of advanced manufacturing capability with digital intelligence.

Traditional manufacturing is primarily characterized by standardized, high-volume production with an emphasis on cost minimization and efficiency through specialization and scale. Production processes rely heavily on fixed machinery and human experience, with limited real-time information integration and weak system adaptability. Decision-making is largely centralized and rule-based, and production optimization follows predefined procedures aimed at ensuring process stability and product quality. Typical technologies include conventional machining, casting, forming, and computer numerical control (CNC) equipment. As summarized in Table. 1, traditional manufacturing focuses on efficiency and scalability through standardization and lean manufacturing practices.

With the development of information and communication technologies, smart manufacturing emerged as a transitional paradigm between traditional manufacturing and intelligent manufacturing. The meaning of this concept, however, is not completely uniform across national policy and academic contexts. In the United States, the term "smart manufacturing" is more commonly used. It is generally understood as a fully integrated and collaborative manufacturing system that can respond in real time to changing conditions in factories, supply networks, and customer needs. This understanding emphasizes system integration, real-time responsiveness, supply-chain coordination, and the use of industrial data to support flexible production decisions.

In Germany, the related discussion is more often organized around the concept of Industry 4.0. Rather than treating smart manufacturing as a single enterprise-level technology, Industry 4.0 emphasizes the intelligent networking of machines, products, production processes, and industrial services through information and communication technologies. Its core logic lies in cyber-physical systems, interoperability, vertical and horizontal integration, and data-driven optimization across the industrial value chain. Therefore, the German understanding places particular emphasis on industrial connectivity, standardization, and the integration of manufacturing systems into networked production architectures.

In Japan, the discussion of manufacturing transformation is closely connected with the broader vision of Society 5.0. Under this framework, manufacturing digitalization is not only a matter of improving factory efficiency, but also part of a human-centered social transformation in which cyberspace and physical space are highly integrated. The Japanese perspective therefore gives more attention to how advanced technologies, including artificial intelligence, robotics, big data, and IoT, can support both economic development and the resolution of social problems. In this sense, manufacturing transformation is interpreted within a broader agenda of human well-being, social resilience, and inclusive technological application.

In China, the term "intelligent manufacturing" has become a more formal policy and standardization concept. The Development Plan for Intelligent Manufacturing (2016-2020) defines intelligent manufacturing as a new production mode based on the deep integration of new-generation information and communication technologies with advanced manufacturing technologies. It runs through the whole manufacturing life-cycle, including design, production, management, and service, and is characterized by self-perception, self-learning, self-decision-making, self-execution, and self-adaptation. Compared with the U.S. emphasis on real-time collaborative systems, the German emphasis on cyber-physical industrial networking, and the Japanese emphasis on human-centered social transformation, the Chinese understanding places stronger emphasis on the systematic upgrading of the manufacturing sector, the integration of digital and physical production systems, and the construction of intelligent capabilities across the full production and management process.

Based on these differences, smart manufacturing mainly emphasizes connection, visibility, responsiveness, and data-enabled optimization. Intelligent manufacturing builds upon these foundations but moves further toward autonomous learning, adaptive decision-making, and system-level intelligence. From an international comparative perspective, intelligent manufacturing aims to establish adaptive manufacturing operations and systems by integrating advanced information technology, computing capacity, and artificial intelligence. It depends on the timely acquisition, distribution, analysis, and utilization of real-time data from humans, machines, processes, factories, and product life-cycles. In this dissertation, intelligent manufacturing is therefore understood as a more advanced manufacturing paradigm in which digital connectivity is transformed into intelligent perception, analysis, decision-making, execution, and adaptation. This distinction is also consistent with China's intelligent manufacturing policy and standardization framework. According to the National Intelligent Manufacturing Standard System Construction Guide, intelligent manufacturing is based on the deep integration of advanced manufacturing technology and new-generation information technology, covers the whole product life-cycle including design, production, management, and services, and is characterized by self-sensing, self-decision-making, self-execution, self-adaptation, and self-learning. Therefore, compared with smart manufacturing, intelligent manufacturing places greater emphasis on autonomous decision-making, system-level intelligence, and the coordinated integration of digital, physical, and organizational systems. Table 1.1 clarifies the distinction between traditional manufacturing, smart manufacturing, and intelligent manufacturing from the perspectives of core logic, technological basis, data role, decision-making mode, system scope, and organizational implications.

Table 1.1 Differences Between Traditional Manufacturing, Smart Manufacturing, and Intelligent Manufacturing

Comparison Dimension	Traditional Manufacturing	Smart Manufacturing	Intelligent Manufacturing
Core production logic	Standardized production based on fixed processes, scale efficiency, and human experience	Connected and data-enabled production based on real-time monitoring and flexible response	Adaptive and intelligence-driven production based on perception, learning, decision-making, execution, and adaptation
Main objective	Improve productivity and reduce cost through standardization and process control	Improve responsiveness, flexibility, quality, and coordination through digital connectivity	Improve system-level optimization, autonomous decision-making, and integrated value-chain coordination
Technological basis	Conventional machinery, CNC equipment, manual control, and basic automation	Sensors, IoT, industrial networks, automation systems, cyber-physical connectivity, and data platforms	AI, big data analytics, digital twins, edge/cloud computing, intelligent equipment, industrial software, and human-cyber-physical integration
Role of data	Data are limited, fragmented, and mainly used for post-event recording	Data are collected and connected in real time to support monitoring, coordination, and process optimization	Data are analyzed, learned from, and transformed into adaptive decisions and coordinated execution across the life-cycle
Decision-making mode	Mainly experience-based and rule-based, with strong human dependence	Data-supported decision-making, with digital systems assisting managers and operators	Intelligent and adaptive decision-making, with stronger machine learning, prediction, optimization, and autonomous adjustment
System scope	Mainly workshop-level or production-line-level operations	Factory and supply-chain connectivity, with emphasis on real-time response	Full life-cycle integration covering design, production, management, logistics, service, and cross-enterprise

			collaboration
Organizational implication	Efficiency improvement within relatively stable production routines	Digital coordination and operational visibility across production and supply-chain activities	Organizational capability building through cross-functional coordination, intelligent governance, and continuous adaptation
Relationship to ESG performance	Indirect and limited, mainly through efficiency improvement	Potentially relevant through resource monitoring, process control, and transparency	Directly relevant to ESG through cleaner production, information transparency, green innovation, financing-resource allocation, and synergistic governance

Source: developed by the author

As shown in Table 1.1, the distinction between smart manufacturing and intelligent manufacturing does not lie simply in the adoption of digital technologies. The key difference lies in the depth and scope of intelligence embedded in the manufacturing system. Smart manufacturing emphasizes digital connection, real-time visibility, flexible response, and data-supported optimization. Intelligent manufacturing further emphasizes autonomous learning, adaptive decision-making, coordinated execution, and integrated optimization across design, production, management, logistics, service, and external collaboration. This distinction is particularly important in the Chinese context. While the United States, Germany, and Japan respectively emphasize real-time collaborative manufacturing, cyber-physical industrial networking, and human-centered social transformation, China's concept of intelligent manufacturing is more directly linked to the systematic upgrading of the manufacturing sector and the development of intelligent capabilities across the whole production life-cycle.

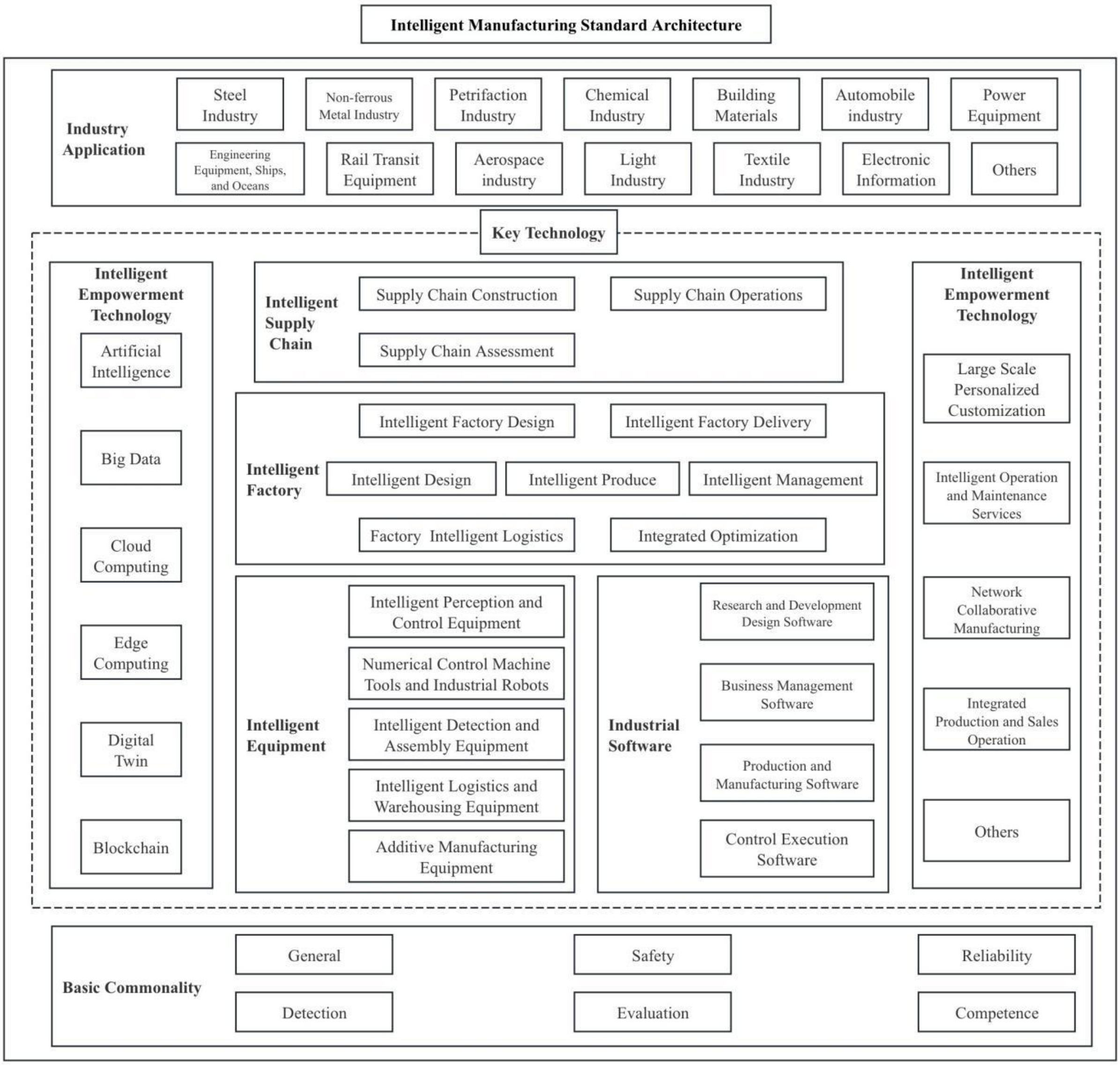
Building upon smart manufacturing, intelligent manufacturing represents a more advanced and comprehensive manufacturing paradigm. The concept of intelligent manufacturing was first proposed by Wright and Bourne (1988), who emphasized the integration of software systems, knowledge engineering, and robotics technologies to enable highly autonomous factory operations. Subsequent studies have further developed this concept by highlighting the incorporation of human intelligence into manufacturing systems through advanced information processing and decision-making capabilities. According to Wang (2020), intelligent manufacturing relies on large-scale data collection through Internet of Things (IoT) sensing systems, centralized data processing, and intelligent decision-making supported by information management systems to continuously optimize production efficiency. In the literature, intelligent manufacturing is generally understood as a production and organizational system in which advanced manufacturing technologies are deeply integrated with next-generation information and communication technologies across the full manufacturing life-cycle. Its distinguishing feature lies not merely in the use of automated equipment or digital tools, but in the ability to enable real-time perception, dynamic interconnection, intelligent analysis, adaptive decision-making, and coordinated execution across design, production, management, logistics, and service.

In the Chinese context, the *Development Plan for Intelligent Manufacturing (2016-2020)* issued by the Ministry of Industry and Information Technology defines intelligent manufacturing as a new production mode based on the deep integration of next-generation information and communication technologies with advanced manufacturing technologies. This mode spans the entire manufacturing life-cycle, including design, production, management, and service, and is characterized by key functions such as self-perception, self-learning, self-decision-making, self-execution, and self-adaptation. Compared with smart manufacturing, intelligent manufacturing places greater emphasis on autonomous decision-making, system-level intelligence, and the seamless integration of digital, physical, and organizational elements.

From a technological perspective, intelligent manufacturing represents an important manifestation of the new industrial revolution. The evolution from Industry 2.0 to Industry 4.0 reflects a paradigm shift from mechanization and automation toward cyber physical integration and intelligent systems. While the first three industrial revolutions primarily liberated human physical labor, the fourth industrial revolution focuses on liberating human cognitive and decision-making capabilities by integrating Cyber Physical Systems (CPS), Internet of Things (IoT), artificial intelligence, and advanced data analytic (Sun et al., 2022). Manufacturing enterprises have accordingly transitioned from traditional manufacturing to smart manufacturing and ultimately toward intelligent manufacturing.

As illustrated in Figure 1.10, intelligent manufacturing is not limited to the factory floor but constitutes a system-wide architecture encompassing intelligent supply chains, intelligent factories, intelligent equipment, and industrial software. At the technological level, intelligent manufacturing is empowered by artificial intelligence, big data, cloud computing, edge computing, digital twin technology, and block-chain. At the application level, it supports intelligent design, intelligent production, intelligent logistics, intelligent management, and integrated optimization across the entire value chain. This architecture enables intelligent manufacturing to operate across multiple industries and supports advanced functions such as large-scale personalized customization, intelligent operation and maintenance services, networked collaborative manufacturing, and integrated production sales coordination.

Figure 1.10 Intelligent Manufacturing Standard Architecture



Source: Intelligent Manufacturing Standard System Construction Guide issued by the Ministry of Industry and Information Technology (MIIT)

Overall, the evolution from traditional manufacturing to smart manufacturing and intelligent manufacturing reflects a continuous deepening of intelligence, from efficiency-oriented production to data-driven optimization and ultimately to autonomous, learning-based decision-making systems. In this dissertation, intelligent manufacturing is defined as a firm-level capability and transformation process through which enterprises integrate intelligent equipment, industrial internet systems, digital platforms, data-driven control mechanisms, and cross-functional coordination arrangements into a unified production and management system. This definition is especially suitable for the present study because it highlights three dimensions that are directly relevant to enterprise ESG performance. First, intelligent manufacturing improves resource efficiency, process control, and cleaner production, which may enhance the environmental dimension of enterprise performance. Second, it strengthens information processing, product traceability, and organizational responsiveness, which may influence the social dimension through better stakeholder interaction and operational accountability. Third, it promotes transparency, internal coordination, and data-based governance, which may affect the governance dimension of enterprise behavior. In this sense, intelligent manufacturing is not treated here as a single technology, but as a multidimensional organizational capability with implications for both economic and sustainability outcomes.

1.2.2 Measurement of Intelligent Manufacturing

The concept of intelligent manufacturing is inherently broad and multidimensional, encompassing technological, organizational, and managerial aspects of manufacturing transformation. Accordingly, different entities and studies adopt diverse perspectives and measurement approaches when operationalizing intelligent manufacturing. Existing literature primarily measures the level of intelligent manufacturing at three levels: the national level, the regional level, and the enterprise level.

Measurement at the National Level

At the national level, two main approaches are commonly employed: the index system method and the proxy indicator method. The index system method constructs a comprehensive evaluation framework composed of multiple indicators across different dimensions, using quantitative techniques such as input-output analysis, analytic hierarchy process, or factor analysis to derive a composite index. For example, Zhou (2015) developed a manufacturing evaluation system consisting of four first-level indicators and eighteen second-level indicators based on four core characteristics of a manufacturing power, industrial scale, industrial structure optimization, quality and efficiency, and sustainable development capacity, and used the resulting composite index to assess the national level of intelligent manufacturing development.

Similarly, Wang and Zhang (2020) employed input-output analysis to construct an Intelligent Manufacturing Index (IMI) and measured both aggregate and industry-specific intelligent manufacturing development levels for G20 countries from 2005 to 2015 using OECD input-output tables. In addition to composite indices, some studies adopt proxy indicators to approximate national intelligent manufacturing levels. A widely used proxy is the density or usage of industrial robots, as reported by the International Federation of Robotics, which has been used by several scholars to capture the degree of intelligent transformation in national manufacturing sectors (Chen and Liu, 2020; Tang and Gu, 2022).

Overall, national-level measures are useful for cross-country comparisons and macro-level analysis, but they are less suitable for examining firm-level behavioral mechanisms due to their high degree of aggregation.

Measurement at the Regional Level

At the regional level, the indicator system method remains the dominant approach. Scholars typically construct regional intelligent manufacturing indices by integrating indicators related to technological infrastructure, industrial development, innovation capacity, and information services. For instance, Dong and Liu (2016) developed an intelligent manufacturing evaluation system based on the technological and economic development levels of Chinese provinces and cities, incorporating indicators such as business performance, innovation capability, product circulation capacity, information service level, patent activity, and logistics infrastructure.

Ji (2021) measured the level of intelligent manufacturing across regions by focusing on infrastructure construction, production application, and market practice dimensions. Wang and Zhang (2021) used principal component analysis to integrate indicators such as total manufacturing output value and manufacturing operating income to construct provincial-level intelligent manufacturing indices. More recently, Xu et al. (2022) proposed a technology-oriented evaluation model emphasizing artificial intelligence development, industrial robot application, Internet penetration, and information communication levels, reflecting the increasing importance of digitalization and intelligent technologies.

Notably, the indicator system approach has been formally institutionalized in China's national standard, *Intelligent Manufacturing Level Evaluation Indicator System and Index Calculation Method* (GB/T 42757-2023), which provides a standardized framework for assessing intelligent manufacturing levels across provinces, autonomous regions, and municipalities. This standardization enhances comparability and policy relevance at the regional level.

Measurement at the Enterprise Level

At the enterprise level, measurement approaches are more diverse, reflecting both data availability constraints and the complexity of firm-level intelligent manufacturing practices. Existing studies mainly adopt five types of methods: indicator system methods, text analysis methods, expert scoring methods, questionnaire survey methods, and policy-based identification methods.

First, the indicator system method evaluates enterprise intelligent manufacturing levels by selecting firm-level indicators related to technology, operations, and performance. For example, Gong (2015) constructed an enterprise intelligent manufacturing evaluation system from three dimensions, ecological environment, development level, and efficiency, using a comprehensive evaluation approach. Yi et al. (2018) further refined enterprise-level measurement by incorporating lifecycle perspective, system level, and intelligent functions based on tensor theory. Wang and Hu (2023) employed panel stochastic frontier analysis to construct an intelligent manufacturing index, capturing enterprises' relative efficiency in intelligent transformation.

Second, text analysis methods have gained increasing popularity due to the availability of unstructured corporate disclosure data. Yang et al. (2020) used Python to crawl annual reports of A-share manufacturing firms, extracted keyword frequencies related to intelligent transformation using the NLTK library, and manually validated samples to ensure accuracy. They further identified the timing of intelligent manufacturing adoption to construct dummy variables. Li et al. (2023) extended this approach by comparing the frequency of intelligent manufacturing related keywords in firm-level annual reports with industry-level benchmarks in the same year to derive a relative intelligent manufacturing index.

Third, the expert scoring method involves constructing an intelligent manufacturing keyword library and relying on expert judgment to assess enterprises' intelligent manufacturing levels based on annual report disclosures. Liu et al. (2022), for instance, applied expert scoring to evaluate the intelligent manufacturing levels of listed manufacturing enterprises in Jiangsu Province and examined the effects of government subsidies and tax incentives.

Fourth, questionnaire survey methods measure intelligent manufacturing by designing multidimensional scales and collecting primary data. Meng and Zhao (2018) conducted a large-scale survey of new energy equipment manufacturing firms across 15 Chinese provinces, measuring intelligent manufacturing from manufacturing and intelligence dimensions. Zhou et al. (2022) followed a "cognition–behavior–effect" framework and contingency logic to construct survey items across multiple dimensions, including digital management capability.

Finally, some studies adopt policy-based identification methods, using government policy implementation as an external signal of intelligent manufacturing adoption. For example, Quan et al. (2022) and Yin et al. (2022) identified intelligent manufacturing firms based on whether they were included in the official list of *Pilot Demonstration Projects for Intelligent Manufacturing* published by the Ministry of Industry and Information Technology.

Methodological Implications for This Dissertation

In summary, existing measurement approaches to intelligent manufacturing vary significantly across levels and methodologies, each with distinct advantages and limitations. National-level and regional-level indices are suitable for macro analysis, while enterprise-level measures are more appropriate for examining enterprise behavior and micro-level mechanisms. Given the research objectives of this dissertation namely, to analyze the impact of intelligent manufacturing on enterprise ESG performance and to identify firm-level transmission mechanisms, enterprise-level measurement methods based on publicly available firm disclosures and quantitative indices are particularly relevant. Accordingly, this dissertation adopts an enterprise-level intelligent manufacturing measure consistent with existing literature and aligned with the theoretical framework developed in the preceding sections.

1.2.3 Impact of Intelligent Manufacturing

As a result of the deep integration of information technology and advanced manufacturing technologies, intelligent manufacturing has become a key driver of manufacturing upgrading and industrial transformation. Existing literature has extensively examined the economic consequences of intelligent manufacturing, with particular attention to its effects on enterprise innovation and production performance. However, the findings are not always uniform, reflecting differences in implementation stages, industry characteristics, and firm heterogeneity.

Impact of Intelligent Manufacturing on Enterprise Innovation

A large body of empirical research suggests that intelligent manufacturing can promote enterprise innovation by improving information accessibility, reducing uncertainty, and enhancing organizational learning capabilities. Li et al. (2023) show that the adoption of intelligent manufacturing enables enterprises to obtain real-time supply chain information and customer demand data, which helps managers reduce uncertainty in innovation decision-making and improve innovation efficiency. Similarly, Meng and Zhao (2022) find that the innovation-enhancing effects of intelligent manufacturing are more pronounced in technology-intensive industries, where firms are better positioned to absorb and utilize intelligent technologies.

From an organizational perspective, Su and Fu (2023), drawing on enterprise growth theory, argue that intelligent technologies facilitate organizational restructuring and coordination, thereby creating favorable conditions for innovation activities. Recent studies further extend this line of research to green innovation and transformation. Cai et al. (2025) and Dong et al. (2025) document a significant positive effect of intelligent manufacturing on enterprises' green transformation, with evidence suggesting that this effect is partially mediated by reduced financing constraints (Yin and Li, 2022) and increased knowledge diversification (Deng and Jiang, 2022).

Nevertheless, not all studies report uniformly positive effects. Some scholars argue that the innovation impacts of intelligent manufacturing may vary across implementation stages and firm life cycles. Meng et al. (2021), based on input-output theory, find that in the early stages of intelligent manufacturing adoption, enterprises often face substantial capital investment requirements, which may crowd out resources available for innovation and temporarily reduce innovation performance. Using a life-cycle perspective, Ding et al. (2023) find that intelligent manufacturing does not significantly affect innovation efficiency for enterprises in the growth and decline stages. Moreover, Hao et al. (2025) identify a significant U-shaped relationship between intelligent manufacturing and industrial green transition, indicating that innovation benefits may only emerge after firms surpass a certain threshold of intelligent manufacturing development, particularly in eastern and non-resource-based regions.

Overall, the existing literature suggests that intelligent manufacturing can enhance enterprise innovation, but the magnitude and direction of this effect depend on enterprises' development stages, resource conditions, and regional contexts.

Impact of Intelligent Manufacturing on Production and Operational Performance

In addition to innovation outcomes, a substantial stream of research focuses on the impact of intelligent manufacturing on production efficiency and operational performance. Zhou et al. (2023) demonstrate that intelligent manufacturing improves total factor energy efficiency through productivity effects, scale effects, and resource allocation effects. Zhu et al. (2023) find that the implementation of intelligent manufacturing has a positive effect on enterprise value creation, reflecting improvements in production efficiency and cost management.

Several studies emphasize the governance and information effects of intelligent manufacturing in shaping operational outcomes. Li and Wang (2022) argue that intelligent manufacturing enhances communication between enterprise management and external stakeholders, thereby strengthening shareholder supervision and alleviating agency conflicts arising from information asymmetry. Consistent with this view, Liu and Wan (2023) find that improved monitoring mechanisms associated with intelligent manufacturing reduce managerial opportunism. These governance improvements translate into tangible operational benefits. Quan and Li (2022) show that intelligent manufacturing reduces enterprises' cost stickiness, while Yue and Gu (2022) demonstrate that intelligent technologies enable enterprises to better acquire market information, dynamically adjust resource allocation, reduce redundancy, and improve cost flexibility.

Recent quasi-natural experiment studies provide further causal evidence. Zhu et al. (2024), using a difference-in-differences approach based on the staggered implementation of intelligent manufacturing pilot projects, find that intelligent manufacturing adoption significantly increases labor productivity among Chinese listed manufacturing firms. Similarly, Liu and Zuo (2025) report positive and robust effects of intelligent manufacturing on firms' labor productivity, reinforcing the view that intelligent manufacturing contributes to improved production performance through efficiency gains and organizational optimization.

Summary and Research Implications

In summary, existing research provides substantial evidence that intelligent manufacturing has significant effects on enterprise innovation and production performance, although these effects may vary across stages of adoption, firm characteristics, and regional contexts. Most studies focus on traditional economic outcomes such as innovation efficiency, productivity, cost structure, and firm value. By contrast, relatively little attention has been paid to the broader non-financial consequences of intelligent manufacturing, particularly its implications for corporate environmental, social, and governance (ESG) performance. This gap highlights the need for a more comprehensive assessment of intelligent manufacturing that extends beyond conventional performance metrics and incorporates sustainability and governance dimensions, an issue that the present study seeks to address.

Existing studies have generally emphasized the positive effects of intelligent manufacturing on productivity improvement, process optimization, resource efficiency, and operational stability. However, the broader impact of intelligent manufacturing should not be interpreted only from an efficiency-enhancing perspective. The introduction of automation, intelligent equipment, and data-driven production systems may also generate adjustment costs and organizational risks. For example, it may reduce the demand for repetitive labor, create skill mismatch among employees, and increase pressure for workforce restructuring. Large-scale digital investment may also intensify short-term financial pressure, especially when transformation benefits cannot be realized immediately. In addition, data integration and platform-based decision-making may change existing responsibility boundaries among production, technology, finance, compliance, and human-resource departments, thereby creating internal coordination tensions.

These potential effects suggest that the sustainability value of intelligent manufacturing depends not only on technological upgrading itself, but also on how enterprises manage the accompanying labor adjustment, governance coordination, data responsibility, and risk-control issues. If intelligent manufacturing is treated only as a tool for cost reduction or labor substitution, its social and governance value may be limited. By contrast, when intelligent transformation is supported by employee reskilling, responsible organizational adjustment, and coordinated governance arrangements, efficiency improvement is more likely to be translated into substantive ESG improvement. This provides an important basis for examining intelligent manufacturing not merely as a technical investment, but as an organizational transformation process with environmental, social, and governance implications.

1.3 Enterprise ESG Performance Related Literature Review

1.3.1 Conceptual Evolution and Definition of Enterprise ESG Performance

ESG is an acronym for Environmental, Social, and Governance. The ESG concept has a long intellectual history and can be traced back to the early twentieth century, particularly to the emergence of ethical investment practices. As early as 1924, Oliver Sheldon introduced the concept of Corporate Social Responsibility (CSR), which is widely regarded as the earliest systematic articulation of enterprises' social responsibilities and laid an important foundation for the subsequent development of ESG related ideas.

During the 1980s, large-scale movements opposing South Africa's apartheid regime marked a critical stage in the evolution of socially responsible investment. At that time, investment funds totaling approximately USD 625 billion adopted ethical screening strategies that excluded companies associated with apartheid from their portfolios. This value-based screening approach contributed significantly to the formation and diffusion of the concept of Socially Responsible Investment (SRI). In the 1990s, rising living standards were accompanied by increasingly severe environmental pollution, and the degradation of ecosystems heightened public awareness of environmental protection. As a result, environmental concerns were gradually incorporated into value-based investment frameworks. Subsequently, the Asian financial crisis in 1998 and a series of corporate governance scandals in the early 2000s, including financial fraud and labor discrimination in developed economies, intensified demands for improved corporate governance, further enriching the connotation of ESG investment.

Since the beginning of the twenty-first century, the ESG investment framework has gradually taken shape. In 2004, the United Nations Environment Programme (UNEP) released the report *Who Cares Wins*, which formally introduced the ESG concept and advocated the integration of environmental, social, and governance factors into corporate strategic investment decisions. In 2006, the United Nations Principles for Responsible Investment

(PRI), jointly launched by UNEP and the UN Global Compact, sought to embed ESG considerations into investment processes and align them with capital market practices. The release of the PRI marked a milestone in the global development of ESG and played a decisive role in promoting the widespread adoption of ESG investment principles. Since then, international organizations have continuously refined ESG concepts and frameworks, providing theoretical support and normative guidance for sustainable and responsible investment.

In China, ESG practices have also developed rapidly in recent years. In 2017, the Asset Management Association of China released the first *ESG Responsible Investment Survey* targeting the fund industry, aiming to promote ESG awareness and encourage its integration into domestic investment practices. In 2018, the inclusion of A-share listed firms in the MSCI Emerging Markets Index and MSCI Global Index required Chinese listed companies to undergo ESG rating assessments. In the same year, the revised *Code of Corporate Governance for Listed Companies* issued by the China Securities Regulatory Commission formally established an ESG information disclosure framework, marking the institutionalization of ESG disclosure requirements in China (Shao et al., 2025).

The announcement of China's "carbon peaking and carbon neutrality" goals in 2020 further elevated the prominence of ESG practices and significantly expanded the scope of ESG development (Shi and Wang, 2023). In 2023, the State-owned Assets Supervision and Administration Commission (SASAC) officially released the *China Chengtong ESG Evaluation System*, the first ESG evaluation framework issued by a central state-owned enterprise, aiming to build an ESG ecosystem with Chinese characteristics. In June 2024, SASAC emphasized in the *Guiding Opinions on Central Enterprises Fulfilling Social Responsibilities with High Standards* in the New Era that firms should enhance ESG governance capabilities and performance to proactively address opportunities and challenges arising from ESG development.

In terms of disclosure practices, as of June 10, 2024, a total of 2,082 A-share listed companies had released ESG reports, accounting for 38.8% of all listed firms, representing an increase of 3.6 percentage points compared with 2023. As an increasing number of Chinese firms place greater emphasis on ESG, the associated economic and social benefits are expected to become more pronounced.

Existing studies generally agree that enterprises should not focus solely on financial performance, but should also comprehensively consider environmental protection, social responsibility, and corporate governance factors in their operational activities to achieve high-quality and sustainable economic development (Lu, 2023; Li et al., 2023; Chen and Wang, 2024; Hu, 2025). The ESG framework consists of three core dimensions, environmental (E), social (S), and governance (G), which jointly determine enterprises' sustainable development capacity (Wu and Chen, 2022; An et al., 2024; Li, 2024). From an investment perspective, ESG represents both an investment philosophy and an evaluation standard that assesses enterprises' non-financial performance in environmental, social, and governance domains to determine their long-term investment value (Khan, 2019).

Specifically, the environmental dimension focuses on enterprises' impacts on natural ecosystems, emphasizing carbon emission reduction, energy efficiency improvement, resource utilization optimization, and effective pollution control. The social dimension concerns enterprises' interactions with stakeholders, including governments, investors, suppliers, employees, and consumers, and highlights business ethics, legal compliance, employee and consumer protection, and contributions to social equity and stability. The governance dimension relates to enterprises' internal governance structures, such as board independence, executive compensation mechanisms, shareholder rights protection, information disclosure transparency, and anti-corruption and compliance systems, which collectively ensure transparent, efficient, and sustainable corporate operations.

The ESG concept encompasses three closely related but distinct elements: ESG disclosure, ESG performance (or ESG outcomes), and ESG investment. ESG disclosure refers to the extent and quality of enterprises' information disclosure regarding environmental, social, and governance issues (Wu and Pei, 2023; Jiang and Yao, 2023). ESG performance reflects enterprises' comprehensive outcomes in environmental protection, social responsibility, and corporate governance (Truant et al., 2023; Dong and Sun, 2023). As both ESG disclosure and ESG performance focus on firm-level practices, they are often collectively referred to as ESG practices. In contrast, ESG investment primarily concerns investors and examines how ESG factors influence investment decisions and capital allocation (Chen and Zhang, 2022; Yao, 2024).

This dissertation focuses specifically on ESG performance. As an important non-financial indicator, ESG performance conveys enterprises' long-term value orientation and sustainable development capacity to investors, regulators, and the broader public. Strong ESG performance not only helps enterprises mitigate operational and compliance risks, but also enhances market credibility, strengthens competitive advantages, and generates stable long-term returns for investors.

1.3.2 ESG Rating Systems and Measurement of Enterprise ESG Performance

Since 2015, China's ESG rating system has developed rapidly by drawing on international ESG evaluation principles while adapting them to China's development stage, institutional environment, regulatory priorities, and social expectations. This adaptation is not merely a technical adjustment of rating indicators. It reflects the fact that corporate sustainability in China is evaluated not only from the perspective of investor risk management, but also from the perspective of whether enterprises contribute to the country's broader development objectives.

In mature capital markets, ESG evaluation is often closely associated with financial materiality, investor protection, risk exposure, and cross-market comparability. In the Chinese context, however, ESG is also connected with high-quality development, ecological civilization, industrial upgrading, social stability, and coordinated development among multiple stakeholders. This means that Chinese ESG evaluation places stronger emphasis on the compatibility between corporate behavior and national development priorities. Environmental responsibility is closely related to pollution control, resource conservation, energy efficiency, green manufacturing, and the dual-carbon goals. Social responsibility is not limited to charitable donation or community relations, but also includes stable employment, employee protection, product quality, consumer rights, supply-chain responsibility, data security, and enterprises' contribution to broader social development. Governance responsibility emphasizes not only board structure and shareholder protection, but also regulatory compliance, information disclosure, risk prevention, business ethics, and the coordination of interests among shareholders, employees, suppliers, customers, communities, regulators, and other stakeholders.

Therefore, ESG measurement in China should not be understood as a direct replication of international ESG scoring models. It reflects a more development-oriented, responsibility-oriented, and coordination-oriented understanding of corporate sustainability. This contextual logic explains why domestic ESG rating systems are particularly relevant for evaluating Chinese listed companies. Against this background, major domestic ESG rating systems include Huazheng ESG Rating, Zhongzheng ESG Rating, and Wind ESG Rating, among others.

International ESG Rating Systems

In international capital markets, developed economies in Europe and North America were among the first to explore responsible investment practices and to establish ESG evaluation frameworks. Widely used international ESG rating systems include the Dow Jones

Sustainability Index (DJSI), MSCI ESG Ratings, FTSE Russell ESG Ratings, Bloomberg ESG Ratings, Sustainalytics, and Refinitiv.

The Dow Jones Sustainability Index, launched by Dow Jones in 1999, is one of the earliest ESG based indices. It evaluates enterprises' comprehensive sustainability performance across dimensions such as corporate governance, risk management, brand management, climate change mitigation, supply chain standards, and labor practices. A distinctive feature of the DJSI is its industry-specific weighting scheme, which adjusts indicator weights according to industry characteristics, thereby enhancing comparability across different sectors.

MSCI ESG Ratings focus on the three core ESG pillars, Environmental, Social, and Governance, and incorporate a set of core indicators covering issues such as environmental protection, labor relations, board structure, and corporate ethics. MSCI's rating methodology emphasizes exposure to ESG risks and enterprises' ability to manage such risks relative to industry peers, making it widely used in global investment decision-making and cross-market comparisons.

Other international systems, such as Bloomberg ESG Ratings, leverage extensive data collection and analytical capabilities to provide data-driven, frequently updated ESG assessments that are seamlessly integrated into financial analysis platforms. These international ESG ratings have played an important role in promoting ESG standardization, improving information transparency, and facilitating global capital allocation toward sustainable assets.

ESG Rating Systems in China

Since 2015, China's ESG rating system has developed rapidly. Building upon international standards while adapting to domestic institutional conditions, Chinese ESG rating agencies have continuously refined their evaluation frameworks to better reflect the characteristics of China's capital market and regulatory environment. Major domestic ESG rating systems include Huazheng ESG Rating, Zhongzheng ESG Rating, and Wind ESG Rating, among others.

The Huazheng ESG Rating was introduced by Shanghai Huazheng Index Information Service Co., Ltd. in 2019. Unlike the commonly used three-tier ESG indicator systems adopted by international agencies, the Huazheng ESG framework is structured into four levels, incorporating China-specific regulatory requirements and market practices. Its key advantages include broad firm coverage, high data timeliness, and strong relevance to China's institutional context.

In 2020, China Securities Index Co., Ltd. launched the Zhongzheng ESG Rating, which adopts a three-tier indicator system and incorporates factors such as carbon emissions, charitable activities, and the impact of corporate controversies. This framework emphasizes both enterprises' ESG practices and their exposure to negative ESG events. In 2021, Shanghai Wind Information Technology Co., Ltd. officially released the Wind ESG Rating, which evaluates enterprises from the perspective of financial materiality. The Wind ESG framework consists of management practice assessments and controversy event evaluations, aiming to comprehensively capture enterprises' ESG management capabilities and major unexpected risks.

Comparison Between International and Domestic ESG Ratings

Recent studies have compared the effectiveness of international and domestic ESG rating systems in the Chinese context. Chen et al. (2025) systematically compared ESG ratings provided by global agencies and local Chinese raters to assess their ability to capture ESG risks faced by Chinese firms. Their findings indicate that the Huazheng ESG Rating outperforms MSCI ESG Ratings in predicting ESG related negative events among Chinese listed companies. In the Chinese capital market context, the Huazheng ESG rating provides a locally adapted and relatively systematic measurement of enterprise ESG performance. The Huazheng methodology refers to mainstream international ESG evaluation practices while incorporating China's institutional environment, information disclosure conditions, and securities market characteristics. Therefore, compared with purely international ESG ratings, it is more suitable for evaluating Chinese A-share listed companies. Importantly, the Huazheng ESG rating should not be understood as a simple single-score judgment. According to the Huazheng ESG Ratings Methodology V2.1, the rating is constructed by aggregating the Environmental, Social, and Governance pillars, and each pillar is further decomposed into specific themes and issue indicators. The detailed indicator composition, weighting logic, industry adjustment, and empirical transformation of the Huazheng ESG rating are further explained in Section 2.2.2.

The comparison between international and domestic ESG rating systems also suggests that ESG ratings should not be regarded as fully interchangeable measures. Although most rating systems are organized around the three broad pillars of Environment, Social, and Governance, they differ in indicator coverage, scoring scale, weighting logic, industry adjustment, data sources, and institutional orientation. Some systems use letter grades or ordered numerical scores, while others adopt percentage scores, percentile rankings, or composite index values. Therefore, differences across ESG ratings are not merely differences in numerical expression. They may reflect different judgments about which ESG issues are more material, which stakeholders should be emphasized, and how corporate sustainability should be evaluated in a particular institutional context.

This distinction is important for the present dissertation. Since the empirical analysis focuses on Chinese A-share listed companies, ESG performance should be measured and interpreted within a rating framework that is consistent with China's capital market environment, disclosure practices, regulatory expectations, and stakeholder structure. Therefore, the use of a domestic ESG rating system ensures that the dependent variable is aligned with the institutional setting and research object of this dissertation.

Implications for ESG Measurement in This Dissertation

Taken together, existing ESG rating systems differ in indicator selection, weighting schemes, data sources, and institutional orientation. International ratings are well suited for global comparisons, whereas domestic ESG ratings may offer greater contextual relevance when analyzing enterprises operating within China's specific regulatory and market environment. Given the research objectives of this dissertation and the focus on Chinese A-share listed companies, this dissertation adopts the Huazheng ESG Rating as the primary measure of enterprise ESG performance. As an important non-financial indicator, ESG performance conveys enterprises' long-term value orientation and sustainable development capacity to investors, regulators, and the broader public. A strong ESG performance not only helps enterprises mitigate operational and compliance risks, but also enhances market credibility, strengthens competitive advantages, and supports long-term value creation.

1.3.3 Determinants of Enterprise ESG Performance

Enterprise ESG performance is influenced by a wide range of factors operating at multiple levels, including enterprises' internal governance structures and strategic orientations, industry and market environments, as well as macro-level policies and international norms. Accordingly, existing literature generally categorizes the determinants of ESG performance into three interrelated dimensions: micro-level, meso-level, and macro-level factors.

Micro-Level Determinants

At the micro level, managerial characteristics, corporate governance mechanisms, enterprise innovation capability, and investor attention play critical roles in shaping ESG outcomes. Prior studies highlight the importance of managerial attributes in promoting ESG practices. Campopiano et al. (2023) argue that female executives are more inclined to integrate ESG principles into corporate decision-making, while empirical evidence from China confirms that female directors significantly enhance enterprise ESG performance (Li &

Luo, 2024). Similarly, executives with overseas backgrounds are found to positively affect enterprises' ESG performance by introducing international norms and sustainability-oriented management practices (Bu & Geng, 2023; Sun & Zhang, 2024). Shi et al. (2024) further demonstrate that independent directors with overseas education experience effectively promote ESG improvement. In addition, CEOs' academic backgrounds also matter, as enterprises led by scholar-type CEOs tend to exhibit stronger ESG performance (Xia et al., 2023).

Corporate governance mechanisms constitute another key micro-level determinant. Ownership structure has been shown to significantly influence ESG outcomes. For instance, the coexistence of multiple large shareholders (Tan & Liu, 2024), the presence of common institutional shareholders (Zhou et al., 2024), and foreign ownership (Chen & Jia, 2025) all contribute to enhanced ESG performance by strengthening monitoring and reducing agency problems. Consistent with this view, Oh et al. (2011) find that institutional investors generally support enterprises' engagement in social responsibility activities, whereas family-controlled enterprises tend to prioritize short-term financial returns and may sacrifice stakeholder interests, thereby weakening ESG performance. Executive compensation incentives also play a positive role, as ESG linked or performance-based remuneration schemes motivate managers to pursue sustainable practices and long-term value creation (Cohen et al., 2023; Wang et al., 2024). Moreover, enterprises' intrinsic preferences for social responsibility and environmental protection can shape managerial behavior and encourage proactive ESG engagement (Banerjee et al., 2022).

Enterprise innovation capability is another important determinant of ESG performance. Innovation capacity directly affects enterprises' ability to invest in environmental protection and social responsibility initiatives. In particular, green technological innovation and digital transformation have been shown to significantly improve environmental and social outcomes (Porter & van der Linde, 1995). Empirical studies indicate that digital technological innovation enhances enterprise ESG performance (Yang & Yang, 2024), while broader digital transformation contributes to ESG improvement by increasing total factor productivity (Han & Zhang, 2023), promoting knowledge sharing and agglomeration, and stimulating green innovation (Bai et al., 2023). In addition, emerging digital technologies such as block-chain have been found to significantly improve ESG performance by enhancing transparency and traceability (Hu, 2023). Finally, investor attention serves as an important external governance mechanism. Based on web search data, Chen and Liu (2023) find that heightened investor attention is associated with improved enterprise ESG performance.

Meso-Level Determinants

At the meso-level, industry characteristics and market environments shape enterprises' ESG related competitive pressures and benchmark standards. Industry attributes significantly influence ESG strategies. Enterprises operating in highly polluting industries, such as energy and chemicals, are subject to stricter environmental regulation and public scrutiny, which incentivizes the adoption of green technologies and enhanced environmental management practices (Clarkson et al., 2011). In contrast, enterprises in technology and financial industries tend to place greater emphasis on social responsibility and corporate governance (Alkaraan et al., 2022). From an overall ESG perspective, Borghesi et al. (2014) find that enterprises in computer hardware and consumer goods industries generally receive higher ESG ratings, whereas enterprises in industries such as aviation and oil exhibit lower ESG scores.

Market competition also plays an important role at the meso-level. In highly competitive markets, enterprises are more likely to improve ESG performance as a means of enhancing brand reputation, attracting ESG oriented investors, and strengthening competitive advantage (Shi et al., 2025). In addition, supply chain management has emerged as a critical driver of ESG practices. Recent studies show that supply chain digitalization significantly enhances enterprise ESG performance by improving transparency, coordination, and sustainability practices across the supply chain (Li & Wang, 2024; Zhang et al., 2025).

Macro-Level Determinants

At the macro level, national institutional environments, green finance policies, international trade rules, and global sustainability initiatives jointly influence enterprise ESG performance. With respect to national contexts, Cai et al. (2016) argue that a country's development stage, cultural norms, and institutional environment are key determinants of enterprises' social responsibility and ESG practices. Green finance policies also exert a profound impact on corporate sustainability strategies. Governments increasingly use financial instruments such as green credit, carbon markets, and sustainable bonds to guide enterprises toward improved ESG performance (Lei et al., 2023; Shu & Tan, 2023). Empirical evidence from China further confirms that green credit policies significantly enhance enterprise ESG performance (Xu & Wang, 2024).

International trade rules further shape enterprises' ESG behavior, particularly as developed economies strengthen ESG related compliance requirements for imported products. For example, the European Union's Carbon Border Adjustment Mechanism (CBAM) requires exporting enterprises to account for carbon emissions embedded in their products, thereby incentivizing enterprises throughout global supply chains to improve environmental management practices. Finally, global sustainability initiatives, such as the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement, have prompted governments to formulate carbon neutrality and climate policies, further encouraging enterprises to adopt sustainable development strategies (Tiwari et al., 2025).

1.3.4 Economic Consequences of Enterprise ESG Performance

With the deepening of global sustainable development initiatives, ESG has become a central concern in enterprise strategic decision-making and capital market evaluation. Examining the economic consequences of ESG performance not only helps clarify its implications for enterprises' long-term competitiveness, but also provides important insights for investors, regulators, and corporate managers. Existing studies mainly investigate the economic consequences of ESG performance from multiple perspectives, including financial performance, firm value, corporate innovation, and firm risk.

ESG Performance and Financial Performance

From the perspective of financial performance, a substantial body of empirical research documents a positive relationship between ESG performance and enterprises' financial outcomes. Velte (2017), using data from major German stock index enterprises during 2010–2014, finds that ESG performance has a significantly positive effect on financial performance, with the governance dimension exerting the strongest impact among the three ESG components. Alareeni and Hamdan (2020), based on firms listed in the S&P 500 index, provide evidence of a positive association between ESG disclosure and Tobin's Q. Nirino et al. (2021) further demonstrate that ESG practices play a positive moderating role in the relationship between managerial conflicts and financial performance. Consistent with stakeholder theory, Abdi et al. (2022) show that improvements in ESG performance contribute to enhanced financial performance.

Related evidence from emerging markets and China further supports these findings. Aydoğmuş et al. (2022) argue that investment in high ESG performance generates financial returns in terms of both profitability and firm value. Empirical studies based on Chinese listed firms also report that ESG performance significantly promotes corporate financial performance (Yan et al., 2023; Du & Kong, 2024). Overall, the literature suggests that ESG engagement is not merely a cost burden but can generate tangible financial benefits for enterprises.

ESG Performance and Firm Value

From the perspective of firm value, numerous studies indicate that superior ESG performance is associated with higher firm valuation. Yoon et al. (2018), Fatemi et al. (2018), and Wu et al. (2022) consistently find that ESG performance plays an important role in enhancing firm value. Using Chinese listed firms, Zhang and Zhao (2019) show that ESG performance significantly improves firm value, with stronger effects observed among non-state-owned firms, smaller firms, and firms operating in non-polluting industries. Wang et al. (2022) further document a significant positive impact of ESG performance on firm value.

Subsequent research highlights the contextual and structural conditions under which ESG affects firm value. Chang and Lee (2022) find that industry characteristics, such as industry concentration and industry growth rate, moderate the relationship between ESG performance and firm value, suggesting that ESG valuation effects vary across competitive environments. Zhou et al. (2022) provide evidence that improvements in ESG performance significantly enhance firms' market value, with financial performance serving as an important mediating channel. More recently, Bai et al. (2025) demonstrate that robust ESG performance strengthens corporate value by enhancing brand equity and optimizing resource allocation, thereby reinforcing firms' long-term competitive advantages.

ESG Performance and Corporate Innovation

From the perspective of corporate innovation, existing research presents both supportive and divergent findings. Domazlicky and Weber (2004) argue that environmental regulation can exert a positive effect on corporate innovation by stimulating enterprises to develop cleaner technologies. Broadstock et al. (2020) suggest that active engagement in ESG activities enhances enterprises' innovation capabilities. Tan and Zhu (2022) further show that enterprises with better ESG performance tend to have a more stable investor base, lower financing costs, and reduced agency conflicts, which strengthen managerial incentives to invest in environmental performance and R&D, thereby promoting innovation. Using data from emerging markets, Long et al. (2023) find that ESG ratings significantly enhance both the quantity and quality of green innovation, with stronger effects observed among enterprises with higher ESG scores.

However, some studies raise concerns regarding potential trade-offs between ESG performance and innovation. Climent and Soriano (2011) argue that increased environmental and social responsibilities may force enterprises to allocate more resources to compliance and environmental governance, potentially reducing profitability and competitiveness and thereby constraining innovation activities. Similarly, Zheng (2023) finds that among enterprises voluntarily disclosing CSR information, CSR disclosure has a significant negative effect on green technological innovation, suggesting that ESG related investments may crowd out innovation resources under certain conditions.

ESG Performance and Firm Risk

From the perspective of firm risk, a growing body of evidence suggests that ESG performance plays a risk-mitigating role. Sassen et al. (2016) show that ESG performance significantly reduces both total risk and idiosyncratic risk, with environmental performance exerting a particularly strong effect on idiosyncratic risk, while total risk reduction is mainly observed in environmentally sensitive industries. Drawing on signaling theory and resource dependence theory, Tan et al. (2022) find that high-quality ESG performance conveys positive signals regarding enterprises' growth prospects, reduces stakeholders' information acquisition costs, and enhances enterprises' ability to access resources from consumers, supply chains, and investors, thereby lowering uncertainty-related risks. Xiao et al. (2021) further argue that ESG ratings serve as an important reference for investors' decision-making, and that strong ESG performance can effectively reduce information risk and operational risk, as reflected in significantly lower audit fees.

Overall, existing literature provides substantial evidence that ESG performance has important economic consequences across multiple dimensions, including financial performance, firm value, innovation outcomes, and risk exposure. While most studies document positive effects, others highlight potential trade-offs, mediating mechanisms, and contextual heterogeneity depending on firm characteristics and industry environments. These mixed findings underscore the need for further research to identify the conditions and mechanisms through which ESG performance affects corporate outcomes. Addressing this gap, the present study examines how intelligent manufacturing, a core production-side technological transformation, shapes enterprise ESG performance and its associated economic consequences.

1.4 Impact of Intelligent Manufacturing on Enterprise ESG Performance Related Literature Review

An emerging strand of literature has begun to directly examine the relationship between intelligent manufacturing and enterprise ESG performance. Gao et al. (2025), Zhang et al. (2025), and Sun et al. (2025) exploit the Intelligent Manufacturing Pilot Projects (IMPP) implemented in China as a quasi-natural experiment to identify the causal effects of intelligent manufacturing on enterprises' ESG outcomes. Using difference-in-differences approaches, these studies consistently find that enterprises participating in the IMPP experience significant improvements in ESG performance, providing important causal evidence that intelligent manufacturing contributes to corporate sustainability.

In addition to policy-based identification strategies, some studies adopt firm-level measurement approaches to capture intelligent manufacturing practices. Huang et al. (2024) employ a text analysis method based on annual reports to proxy enterprises' intelligent manufacturing implementation and document a significant positive effect of intelligent manufacturing on ESG performance. These findings further support the view that intelligent manufacturing plays a critical role in enhancing enterprises' environmental, social, and governance outcomes.

Despite their contributions, existing approaches also exhibit notable limitations. Although the quasi-natural experimental design based on the IMPP offers strong causal identification, it primarily captures whether enterprises participate in intelligent manufacturing initiatives rather than the intensity or heterogeneity of intelligent manufacturing practices across enterprises. As a result, such binary policy indicators may fail to fully reflect continuous differences in enterprises' intelligent manufacturing levels.

Similarly, text-based measurement methods are subject to inherent constraints. Even when carefully constructed keyword dictionaries are used, the frequency of intelligent manufacturing related terms may suffer from contextual ambiguity and disclosure bias. Differences in narrative styles, disclosure incentives, and reporting practices across enterprises can lead to measurement errors, particularly when keyword counts are interpreted as proxies for actual implementation depth. Moreover, as an output-oriented measure, text analysis primarily captures enterprises' disclosure behavior rather than the underlying technological and organizational transformation processes. As noted by Wang and Hu (2023), it remains difficult for text-based methods to precisely identify the "what" and "how" of intelligent manufacturing practices, since keyword frequency alone cannot distinguish substantive implementation from symbolic disclosure.

Overall, while existing studies provide valuable initial evidence on the ESG effects of intelligent manufacturing, limitations in measurement precision and mechanism identification suggest the need for further research. In particular, there remains a lack of firm-level analyses that combine continuous measures of intelligent manufacturing with systematic mechanism testing. Addressing these gaps, the present study adopts a comprehensive intelligent manufacturing index to capture firm-level variation and explores multiple transmission channels through which intelligent manufacturing affects enterprise ESG performance.

1.5 Summary of the Chapter

This chapter systematically introduces the research theme of intelligent manufacturing and enterprise ESG performance from multiple perspectives, including the practical background, theoretical background, and research motivation, thereby laying the overall foundation for the subsequent analysis.

First, in the discussion of the research background, this chapter situates the study within the context of the new round of technological revolution, the intelligent transformation of manufacturing, and the deepening of sustainable development initiatives worldwide. It highlights the strategic role of intelligent manufacturing in promoting high-quality corporate development and achieving China's "dual carbon" goals. At the same time, by emphasizing the evolution of ESG from a "soft constraint" to a "hard constraint," this chapter illustrates the growing importance of ESG performance in capital markets and corporate governance, thereby underscoring the practical relevance of examining the relationship between intelligent manufacturing and enterprise ESG performance.

Second, through a review of the related literature and the identification of research gaps, this chapter systematically summarizes existing studies on intelligent manufacturing and ESG performance and points out several limitations in the current literature. In particular, prior research has paid insufficient attention to integrated sustainability outcomes, mechanism identification, and empirical analysis under the Chinese institutional context, especially studies based on long-term firm-level data. Against this backdrop, this chapter clearly formulates the core research questions of the dissertation, namely whether intelligent manufacturing affects enterprise ESG performance, through which mechanisms such effects occur, and whether the effects exhibit significant heterogeneity across enterprises and institutional environments.

Third, this chapter clearly defines the research purpose and specific research objectives. It emphasizes that the study aims to identify the impact of intelligent manufacturing on enterprise ESG performance at the firm level, to uncover the internal transmission mechanisms, such as information transparency, green innovation, financing constraints, and synergistic governance, and to further examine heterogeneity in the ESG effects of intelligent manufacturing across regions, firm technological attributes, and different segments of China's multi-tier capital market.

Finally, this chapter outlines the research methods, research significance, and key innovations of the study, as well as its research scope and limitations. It clarifies the potential contributions of the dissertation in terms of research perspective, mechanism analysis, and empirical evidence within the Chinese context, while also objectively acknowledging possible limitations related to variable measurement, causal identification, and sample applicability.

In summary, Chapter 1 establishes the starting point of the dissertation from both theoretical and practical perspectives, clarifies the research questions, research logic, and overall framework, and provides a solid foundation for the development of the theoretical analysis, hypothesis formulation, and empirical investigation in the subsequent chapters.

CHAPTER 2. RESEARCH METHODOLOGY

This chapter outlines the research methodology employed to examine the impact of intelligent manufacturing on enterprise ESG performance. Guided by the theoretical framework developed in Chapter 1, this study adopts a mixed-methods research design that integrates quantitative econometric analysis with qualitative case studies. The chapter systematically introduces the overall research framework and design, data sources and sample selection, variable measurement, econometric model specification, and analytical strategies used to test the proposed hypotheses. By providing a transparent and rigorous methodological explanation, this chapter ensures the reliability, validity, and replicability of the empirical findings, and establishes a solid foundation for the subsequent results and discussion.

2.1 Research Framework and Design

This chapter elaborates the research methodology adopted to examine the impact of intelligent manufacturing on enterprise ESG performance. Guided by the theoretical foundations established in Chapter 1, this dissertation employs a mixed-methods research design that integrates quantitative econometric analysis with qualitative case studies. Such a design is consistent with the requirements of causal research and enables a comprehensive investigation of both the magnitude of the effect and the underlying transmission mechanisms.

From a methodological perspective, this study belongs primarily to causal quantitative research, supplemented by qualitative analysis for validation and interpretation. The core objective is to identify whether intelligent manufacturing causally affects enterprise ESG performance, through which internal mechanisms this effect operates, and whether the effect exhibits heterogeneity across different institutional and firm-level contexts.

The overall research framework follows a clear logical sequence: theoretical foundation to research questions and hypotheses to empirical model design to variable measurement to data analysis to robustness and heterogeneity testing to qualitative case verification. Intelligent manufacturing serves as the key explanatory variable, enterprise ESG performance as the dependent variable, and information transparency, green innovation, financing constraints, and synergistic governance as mediating variables. Firm characteristics, financial indicators, and governance variables are incorporated as control variables. This integrated framework ensures internal consistency between theory, hypotheses, and empirical strategy, and provides a clear intellectual map for the empirical analysis.

2.1.1 Overall Research Framework

This dissertation develops an integrated research framework to systematically examine the impact of intelligent manufacturing enterprise ESG performance. The overall research logic is constructed around a clear analytical chain linking research questions, theoretical foundations, hypothesis development, and empirical methods, ensuring internal coherence and methodological rigor.

Specifically, the dissertation is guided by three core research questions: (1) whether intelligent manufacturing significantly affects enterprise ESG performance; (2) through which internal mechanisms intelligent manufacturing influences ESG outcomes; and (3) whether such effects exhibit heterogeneity across enterprises with different characteristics and institutional environments. These research questions are translated into testable hypotheses grounded in multiple theoretical perspectives, including the Resource-Based View, Stakeholder Theory, Information Asymmetry Theory, Green Innovation Theory, and Institutional Theory. Each theory provides a distinct yet complementary lens to explain the relationship between intelligent manufacturing and enterprise ESG performance.

At the empirical level, intelligent manufacturing is treated as the core explanatory variable, while enterprise ESG performance serves as the primary outcome variable. Information transparency, green innovation, financing constraints, and synergistic governance are incorporated as key mediating mechanisms to open the “black box” of how intelligent manufacturing translates into ESG improvements. Furthermore, heterogeneity analyses are conducted across regions, firm technological attributes, and listing boards to capture the conditional effects of intelligent manufacturing under different institutional and market contexts.

Methodologically, this dissertation adopts a comprehensive research paradigm that integrates theoretical analysis, large-sample empirical testing, mechanism analysis, heterogeneity analysis, and case-based supplementary evidence. Theoretical analysis provides the conceptual foundation and hypothesis justification; empirical analysis based on firm-level panel data offers systematic statistical evidence; mechanism analysis identifies the internal transmission channels; heterogeneity analysis reveals structural differences in effect intensity; and case studies serve as qualitative complements that enhance the interpretability and realism of the empirical findings.

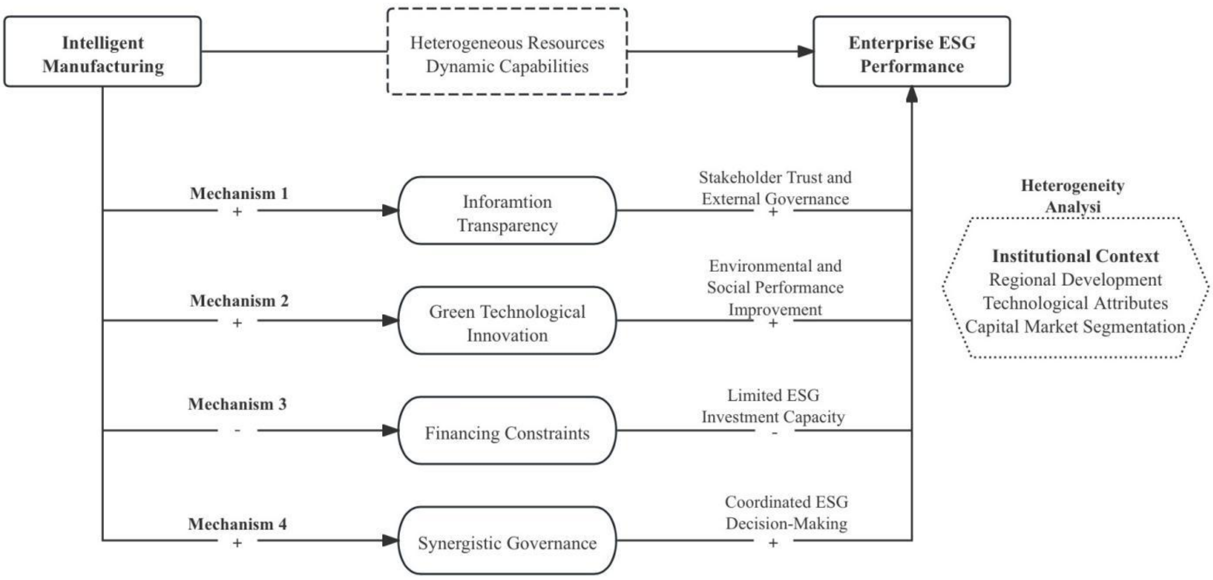
By organizing these components into a unified analytical structure, the research framework ensures that each methodological step directly serves the research questions and objectives. To enhance clarity and transparency, the overall research design is summarized in a schematic research framework figure, which visually illustrates the core analytical path of this dissertation.

The design of the research framework (shown in Figure 2.1) in this dissertation follows a principle of analytical hierarchy and empirical operability. Given the complexity of the relationship between intelligent manufacturing and enterprise ESG performance, the framework intentionally prioritizes theoretical perspectives that directly support causal inference and model construction, while treating other relevant theories as complementary lenses for interpretation. This design choice reflects an effort to balance theoretical completeness with methodological clarity.

In particular, the framework is structured around a parsimonious causal chain that can be explicitly operationalized and empirically tested using firm-level panel data. The selection of core theoretical foundations is therefore guided not by the breadth of the literature reviewed, but by their explanatory relevance to the key variables and mechanisms specified in the econometric models. Theories that primarily inform contextual interpretation, boundary conditions, or mechanism justification are incorporated at later stages of the analysis, such as heterogeneity examination and discussion, rather than being embedded in the central framework.

By adopting this hierarchical approach, the research framework avoids conflating causal structure with contextual explanation and ensures a clear alignment between theory, hypotheses, and empirical strategy. This separation enhances the transparency of the research design and facilitates a more focused examination of how intelligent manufacturing influences enterprise ESG performance under different organizational and institutional conditions.

Figure 2.1 Research Framework



Source: Developed by the author

Figure 2.1 presents the overall research framework of this dissertation. Grounded in the Resource Based View, Stakeholder Theory, and Information Asymmetry Theory, the framework illustrates the causal relationship between intelligent manufacturing and enterprise ESG performance. Intelligent manufacturing is conceptualized as the core explanatory variable, which directly influences enterprise ESG performance and indirectly affects it through four mediating mechanisms: information transparency, green innovation, financing constraints, and synergistic governance. These mechanisms reflect the internal resource optimization, technological upgrading, financial conditions, and governance coordination channels through which intelligent manufacturing contributes to sustainable corporate development. In addition, heterogeneity analysis is incorporated to examine whether the impact of intelligent manufacturing on ESG performance varies across regions, technological attributes, and capital market segments. The framework is empirically tested using panel data econometric models and supplemented by qualitative case studies, ensuring both analytical rigor and practical relevance.

2.1.2 Theoretical Foundations Supporting the Research Design

The research design of this dissertation is derived from the integrated theoretical framework developed in Chapter 1. Consistent with that framework, the empirical strategy is organized around three analytical tasks: testing the overall effect of intelligent manufacturing on enterprise ESG performance, identifying the principal mechanisms through which this effect operates, and examining the conditions under which the effect varies across enterprises.

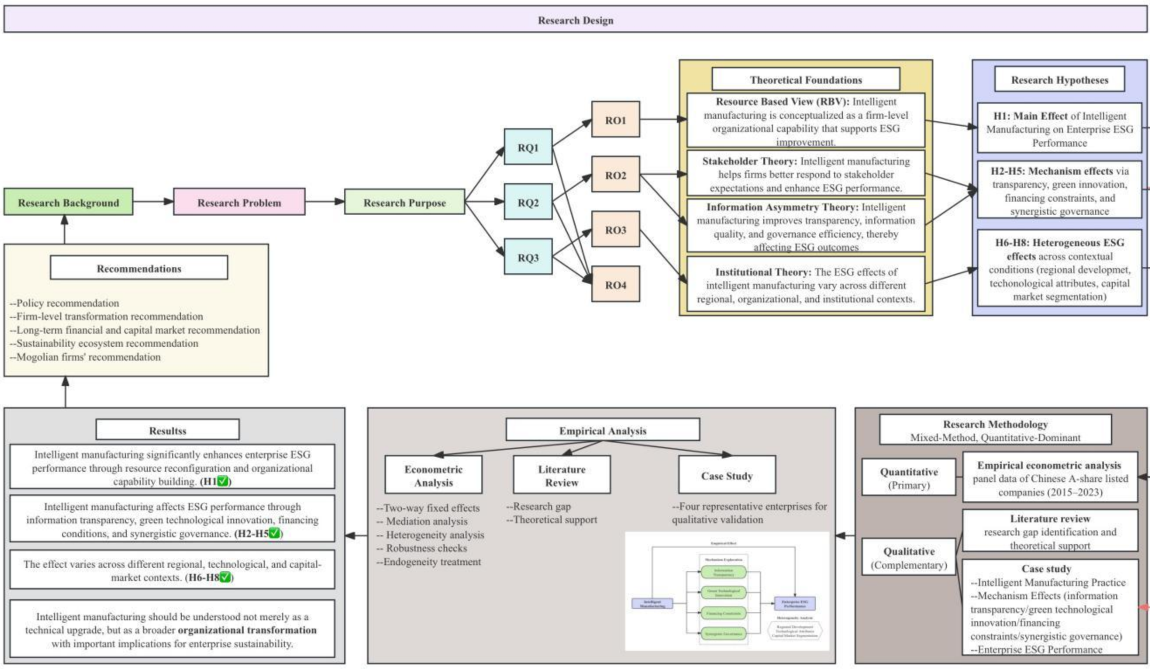
Accordingly, the quantitative design combines baseline regression, mediation analysis, and heterogeneity analysis, while the qualitative case component is used to support mechanism interpretation and contextual understanding. In this way, the methodological design follows the theoretical logic of the dissertation rather than treating theory and empirical strategy as separate components.

More specifically, the baseline regression model is used to establish the general relationship between intelligent manufacturing and enterprise ESG performance. The mediation models are designed to open the “black box” of the relationship by examining whether information transparency, green technological innovation, financing constraints, and synergistic governance operate as the main transmission channels. Among these mechanisms, synergistic governance is intended to capture the governance-structure dimension of intelligent transformation, especially the extent to which digital integration reduces organizational fragmentation and improves coordinated ESG execution across departments and stakeholder interfaces. The heterogeneity analysis then extends the design by testing whether the identified relationship varies across different regional settings, technological attributes, and capital-market segments. The qualitative case studies further complement the econometric analysis by illustrating how these mechanisms operate in concrete organizational settings.

Taken together, this design ensures a close correspondence between theoretical reasoning, hypothesis structure, and empirical implementation, thereby enhancing the internal coherence of the dissertation.

To present the logic of the dissertation in a concise and integrated way, Figure 2.2 summarizes the overall research design. The figure links the research background and problem to the research questions, objectives, theoretical foundations, hypotheses, methods, and final analytical outputs, thereby showing how the study is organized from problem identification to empirical examination and conclusion development.

Figure 2.2 Research Design



Source: Developed by the author

As shown in Figure 2.2, the dissertation follows a sequential and internally connected design. The research background and problem define the starting point of the study, from which the research purpose, questions, and objectives are derived. These are then connected to the theoretical foundations and corresponding hypotheses, which guide the empirical strategy of the dissertation. The figure further shows that the study adopts a mixed-methods, quantitative-dominant design. The quantitative analysis is used to examine the overall effect of intelligent manufacturing on enterprise ESG performance, the mediating roles of information transparency, green technological innovation, financing constraints, and synergistic governance, as well as heterogeneity across regional, technological, and capital-market contexts. The qualitative case analysis complements these tests by providing contextual interpretation and practical validation. Taken together, the figure presents a closed research logic: it moves from background-driven problem identification to theory-based hypothesis development, empirical testing, conclusion synthesis, and implication generation. It therefore serves as both a conceptual guide and a methodological road map for the subsequent sections.

2.2 Quantitative Research

To empirically examine the impact of intelligent manufacturing on enterprise ESG performance and to rigorously test the proposed hypotheses, this dissertation adopts a quantitative research approach based on firm-level panel data. Quantitative analysis allows for systematic identification of causal relationships and mechanism pathways while controlling for firm-specific heterogeneity and macroeconomic shocks. Given the multidimensional nature of ESG performance and the complex transmission channels through which intelligent manufacturing may exert its effects, a structured econometric framework is necessary to ensure robust inference.

Building upon the theoretical foundations established in the previous section, this dissertation constructs a comprehensive empirical model centered on the relationship between intelligent manufacturing and enterprise ESG performance. The quantitative research design integrates baseline regression analysis, mediation effect testing, and heterogeneity analysis to capture both the overall impact and the underlying mechanisms. Firm-level data from Chinese A-share listed companies over the period 2015-2023 are employed, enabling the study to exploit both cross-sectional and inter-temporal variation in intelligent manufacturing adoption and ESG performance.

Specifically, intelligent manufacturing is measured using a firm-level intelligent manufacturing index constructed through stochastic frontier analysis, while ESG performance is proxied by the Huazheng ESG rating. To uncover the internal mechanisms, four mediating variables, information transparency, green innovation, financing constraints, and synergistic governance, are incorporated into the empirical framework. A rich set of control variables is included to account for firm characteristics, ownership structure, and financial conditions. Fixed-effects panel regression models are employed to mitigate unobserved heterogeneity and improve the credibility of the empirical results.

2.2.1 Sample Selection and Data Sources

This dissertation uses Chinese A-share listed firms over the period from 2015 to 2023 as the research sample. To ensure data reliability, comparability, and the validity of empirical results, a series of screening and data-processing procedures are implemented.

First, enterprises designated as ST, *ST, or PT are excluded from the sample. These enterprises are subject to abnormal trading status due to financial distress or operational irregularities, which may lead to distorted financial indicators and atypical governance behavior, making them unsuitable for systematic empirical analysis.

Second, enterprises in the financial and real estate industries are excluded from the final empirical sample. This treatment is adopted to ensure sample comparability and the interpretability of the core variables. The key explanatory variable in this dissertation is a firm-level intelligent manufacturing index, which captures how production-related inputs are transformed into operational outcomes through intelligent transformation. This measurement logic is closely related to physical production processes, production reorganization, and resource-allocation efficiency, and is therefore less applicable to sectors whose value-creation logic differs substantially from production-oriented enterprises. Financial enterprises are excluded because their business models, asset structures, leverage mechanisms, risk exposure, and prudential regulatory requirements differ fundamentally from those of non-financial enterprises. In such firms, indicators such as leverage, profitability, financing constraints, and governance characteristics have different economic meanings and are not directly comparable with those of ordinary listed companies. Real estate enterprises are excluded because their operations are strongly shaped by land acquisition, project development cycles, pre-sale arrangements, asset revaluation, and macro-regulatory policies. Their financial structure and value-creation process are therefore not closely aligned with the technological and organizational logic of intelligent manufacturing examined in this dissertation. Excluding these two industries helps improve sample homogeneity, strengthen the comparability of key variables, and reduce potential estimation bias arising from major sectoral differences. It also ensures that the empirical analysis remains consistent with the dissertation's focus on intelligent manufacturing as a production-side technological and organizational transformation.

Third, enterprise-year observations with missing values for key variables are removed to avoid estimation bias caused by incomplete data.

Fourth, to mitigate the influence of extreme values and potential outliers, all continuous variables are winsorized at the 1st and 99th percentiles. This treatment reduces the impact of abnormal observations while preserving the overall distributional characteristics of the data, which is particularly important in large-sample panel regressions.

After applying these screening criteria and data-processing procedures, the final sample consists of approximately 3,603 enterprises and 30,730 firm-year observations.

Regarding data sources, enterprise-level financial and corporate governance data are obtained from the RESSET, WIND, and CSMAR databases, which are widely used and recognized for their accuracy and coverage in studies on Chinese listed companies. Data on enterprise ESG performance are collected from the Huazheng ESG ratings provided by the WIND database, which offer comprehensive coverage, strong institutional relevance to the Chinese market, and high temporal consistency. The combination of multiple authoritative data sources enhances the reliability and robustness of the empirical analysis.

2.2.2 Variable Definitions and Measurement

Theoretical Justification of Variable Selection

The selection operationalizes the core variables of the dissertation in a way that is consistent with the theoretical framework and empirical objectives of the study. Intelligent manufacturing is measured as a continuous firm-level index in order to capture variation in the extent to which enterprises translate intelligent-manufacturing-related inputs into effective operational outcomes. Enterprise ESG performance is measured using the Huazheng ESG rating, which provides a composite indicator of firms' environmental, social, and governance performance. The mediating variables and control variables are then selected to correspond to the mechanism pathways and firm-level conditions identified in the theoretical analysis.

Dependent Variable: Enterprise ESG Performance

The dependent variable in this dissertation is enterprise ESG performance (ESG). It is selected because the central purpose is to examine whether intelligent manufacturing contributes to broader sustainability-oriented corporate outcomes rather than only to operational efficiency or short-term financial performance. From the perspective of Stakeholder Theory, ESG performance reflects the extent to which an enterprise responds to the expectations of multiple stakeholder groups. From the perspective of Institutional Theory, it also reflects the degree to which the enterprise adapts to increasingly formalized norms of environmental responsibility, social accountability, and governance quality. ESG is therefore theoretically more appropriate than a single environmental or financial indicator because it captures the multidimensional sustainability outcome that this dissertation seeks to explain.

This dissertation adopts the Huazheng ESG rating system as the primary data source for measuring enterprise ESG performance. Following Chen et al. (2024), Lu et al. (2024), Wang et al. (2024) and Xiao et al. (2024), the Huazheng ESG index is used as a proxy for enterprise ESG performance. This choice is consistent with the sample scope of the dissertation because the Huazheng ESG rating is specifically designed for China's securities market and provides broad coverage of Chinese A-share listed firms. It also reflects China's institutional environment, regulatory conditions, and corporate information disclosure practices more directly than purely international ESG rating systems. The use of the Huazheng ESG rating is consistent with the way ESG performance is understood in the Chinese institutional context. For Chinese manufacturing-related enterprises, ESG performance is closely linked to cleaner production, low-carbon transformation, resource efficiency, product quality, employee protection, supply-chain cooperation, data security, disclosure credibility, regulatory compliance, and governance coordination. These issues correspond to China's stronger emphasis on green transformation, real-economy upgrading, social responsibility, and coordinated stakeholder relationships. Accordingly, the Huazheng ESG rating is suitable for this dissertation because it captures both the general logic of ESG evaluation and the specific expectations faced by Chinese listed companies. It allows the empirical analysis to measure ESG performance not only as an investor-oriented sustainability risk indicator, but also as an institutionally embedded outcome reflecting enterprises' contribution to high-quality development, ecological responsibility, social responsibility, and governance modernization in China.

According to the Huazheng ESG Ratings Methodology V2.1, the rating system is constructed through a multi-level framework consisting of three first-level pillars, sixteen second-level themes, forty-four third-level issue indicators, nearly eighty fourth-level underlying indicators, and more than 300 bottom-level data indicators. Therefore, although the empirical model uses the comprehensive Huazheng ESG rating as the dependent variable, this variable is not a simple one-dimensional measure. Rather, it is an aggregated outcome derived from a detailed evaluation of firms' environmental responsibility, social responsibility, and corporate governance quality.

The Environmental dimension evaluates firms' environmental risk exposure and environmental risk management capability. It mainly examines whether firms have made effective efforts to reduce the adverse environmental impacts of their operations and whether they have achieved corresponding environmental outcomes. In the Huazheng framework, this dimension includes five themes: climate change, resource utilization, environmental pollution, environmental friendliness, and environmental management. The Social dimension evaluates firms' fulfillment of social responsibilities toward employees, customers, suppliers, communities, rural revitalization, and other stakeholders involved in production and operation. It includes five themes: human capital, product responsibility, supply chain, social contribution, and data security and privacy. The Governance dimension evaluates the influence of firms’ decision-making mechanisms and checks-and-balances mechanisms on sustainable operation. It focuses on the allocation of rights and responsibilities among shareholders, boards of directors, and managers, as well as the institutional arrangements through which firms coordinate relationships with stakeholders. It includes six themes: shareholder rights, governance structure, disclosure quality, governance risk, external sanctions, and business ethics. The detailed indicator framework is summarized in Table 2.1.

Table 2.1 Huazheng ESG Rating Indicator Framework

3 Pillars	**16 Themes**	**44 Key Issues**
Environment (E)	Climate Change	Greenhouse gas emissions
		GHG emissions reduction roadmap
		Response to climate change
	Resource Utilization	Water consumption
		Land use and biodiversity
		Material consumption
	Environmental Pollution	Industrial emissions
		Electronic waste
		Hazardous waste
	Environmentally Friendly	Renewable energy
		Green buildings
		Green factories
	Environmental Management	Sustainable certification
		Environment penalty
		Supply chain management-E
Social (S)	Human Capital	Employee health and safety
		Employee inspiration and development
		Employee relations
	Product Liability	Quality certification
		Recall and complaints
	Supply Chain	Supplier risk and management
		Supply chain relationship
	Community Investment	Inclusion
		Community investment
		Employment
		Technology innovation
	Data Security and Privacy	Data Security and Privacy
Governance (G)	Shareholders’ Interest	Protection of shareholder’s interests
	Governance Structure	ESG governance
		Risk control
		Board structure
		Executive turnover
	Information Disclosure Quality	ESG external assurance
		Credibility of information disclosure
	Governance Risk	Major shareholder behavior

	Solvency Litigation Tax transparency
External Punishment	Various external punishments
Business Ethics	Business ethics Anti-corruption

Source: Huazheng ESG Ratings Methdology V2.1

In terms of indicator assignment, the Huazheng methodology follows quantitative and objective principles. For structured data, indicators are standardized and assigned values according to theoretical benchmarks, practical experience, and relevant national standards. For unstructured data, the rating system uses semantic analysis and natural language processing techniques to identify and evaluate ESG related information. This design improves the objectivity and timeliness of ESG assessment, especially in a context where ESG disclosure among Chinese listed companies is still developing.

In terms of weighting, Huazheng assigns indicator weights by considering industry characteristics and the materiality of ESG issues. Specifically, the methodology first identifies the core issue indicators for each industry, and then evaluates the degree of impact and the time horizon of impact of each issue. Indicators with higher impact and shorter impact horizons receive higher weights, while non-core issue indicators for a given industry may receive a weight of zero. This weighting logic reflects the fact that the materiality of ESG issues differs across industries.

The Huazheng ESG rating further applies an industry adjustment mechanism. After ESG weighted scores are calculated from the bottom up, the scores are standardized within industries. This adjustment does not change the ranking of firms within the same industry, but it improves the comparability and stability of ESG ratings across industries. The V2.1 methodology further introduces industry adjustment and optimizes selected indicators and industry weights with reference to domestic exchange sustainability disclosure guidelines.

The final Huazheng ESG rating includes both standardized ESG scores and categorical rating results. The ESG total score and the scores of first-level, second-level, and third-level indicators are standardized on a 0-100 scale, with higher scores indicating better ESG performance. The categorical ratings range from AAA, AA, A, BBB, BB, B, CCC, CC, to C. Following common practice in empirical research, this dissertation converts the nine categorical ratings into numerical values from 9 to 1, where AAA is assigned a value of 9 and C is assigned a value of 1. Therefore, a higher ESG value in the empirical analysis indicates better overall enterprise ESG performance. This treatment makes the rating information suitable for panel regression analysis while preserving the relative ordering of firms' ESG performance within the Huazheng evaluation framework. Since all sample firms are assessed under the same domestic rating system, the transformed variable provides an internally consistent firm-year measure of ESG performance for Chinese A-share listed companies.

The use of the comprehensive Huazheng ESG rating as the main dependent variable is consistent with the research purpose of this dissertation. Since the dissertation aims to examine whether intelligent manufacturing improves the overall sustainability performance of enterprises, the comprehensive ESG rating provides an appropriate firm-level measure. At the same time, the dissertation does not ignore the multidimensional structure of ESG. The Huazheng comprehensive rating is internally constructed from detailed E, S, and G indicators, and the dissertation further reports supplementary results for the Environmental, Social, and Governance dimensions in the appendices to enhance measurement transparency and robustness.

This measurement captures enterprises' comprehensive sustainability performance rather than isolated environmental or social outcomes, making it well aligned with the research objective of examining the systematic impact of intelligent manufacturing on enterprise ESG performance.

Independent Variable: Intelligent Manufacturing (IM)

Intelligent manufacturing is the core explanatory variable in this dissertation. In conceptual terms, intelligent manufacturing is understood here as a multidimensional firm-level transformation in which advanced manufacturing technologies are deeply integrated with next-generation digital and information technologies across production, management, and service activities. It does not refer simply to the installation of automated equipment or the isolated adoption of digital tools. Rather, it reflects the extent to which an enterprise has developed a production and organizational system characterized by data connectivity, intelligent equipment, process optimization, real-time monitoring, adaptive control, and coordinated decision-making. This definition is consistent with the analytical orientation of the dissertation, which treats intelligent manufacturing not merely as a technical input, but as a broader capability with implications for operational efficiency, information quality, innovation behavior, financing conditions, governance coordination, and ultimately enterprise ESG performance.

The dissertation conceptualizes intelligent manufacturing as a composite organizational capability rather than as a single technological input. In line with the Resource Based View, intelligent manufacturing refers to the integration of advanced manufacturing technologies with digital and information technologies across production, management, monitoring, and coordination processes. A continuous firm-level measure is employed because intelligent manufacturing is not adequately captured by a binary adoption dummy: enterprises differ substantially in the depth, quality, and effectiveness of intelligent transformation. The IM variable is therefore intended to represent variation in the degree to which enterprises internalize intelligent manufacturing as an operational and managerial capability.

Given the multidimensional nature of intelligent manufacturing, its measurement at the enterprise level is inherently challenging. Existing studies have used several alternative approaches, such as policy-based indicators, text-based disclosure measures, and composite evaluation methods. However, these measures often capture only partial aspects of intelligent manufacturing, such as policy inclusion, disclosure intensity, or selected observable dimensions, and may therefore be less suitable for identifying firm-level differences in substantive implementation. For a panel study of the present kind, a more continuous, comparable, and operationally grounded measure is required. For this reason, following Wang and Hu (2023), this dissertation adopts an enterprise-level Intelligent Manufacturing Index (IM) constructed using the Panel Stochastic Frontier Approach (PSFA) as the core explanatory variable. This approach conceptualizes intelligent manufacturing as an efficiency-enhancing production capability and measures the extent to which enterprises transform intelligent manufacturing-related inputs into economic output. In essence, the PSFA based index does not treat intelligent manufacturing as a symbolic label or a single technological proxy; instead, it captures the degree to which enterprises convert intelligent manufacturing investment and labor input into effective operating performance under a frontier-efficiency framework.

In this dissertation, the PSFA based IM index is adopted directly as a firm-year indicator from the CnOpenData database. Its methodological basis is grounded in production efficiency theory. It conceptualizes intelligent manufacturing as a form of technological efficiency improvement, defined as an enterprise's ability to increase output under given intelligent inputs or reduce inputs for a given level of output. Compared with traditional indicator systems or binary policy-based measures, this measurement has several advantages that make it particularly suitable for this dissertation. First, it is multidimensional: it simultaneously incorporates both the input side (intelligent capital and labor) and the output side (operating performance), avoiding one-sided measurement. Second, it is objective: it relies on observable accounting and employment data rather than subjective scoring, expert judgment, or purely narrative disclosure. Third, it is comparable. It generates a continuous enterprise-year index that is comparable across enterprises, industries, and time, which is especially important for panel-data analysis. Fourth, it is conceptually aligned with the dissertation's understanding of intelligent manufacturing as capability building and efficiency enhancing transformation, rather than a simple technological dummy variable.

Specifically, intelligent manufacturing efficiency is estimated using a translog stochastic frontier production function, expressed as:

$$\mathrm{Ln}(Q_{i,t}) = \beta_0 + \beta_1 ln(K_{i,t}) + \beta_2 ln(L_{i,t}) + \beta_3 [ln(K_{i,t})]^2 + \beta_4 [ln(L_{i,t})]^2 + \beta_5 ln(K_{i,t}) ln(L_{i,t}) \quad + (v_{i,t} - u_{i,t}) \quad (2.1)$$

Using the estimated inefficiency term $u_{i,t}$, the intelligent manufacturing index is calculated as:

$$IM_{i,t} = \exp(-u_{i,t}) * 100 \quad (2.2)$$

$Q_{i,t}$ denotes firm output, measured by annual operating revenue, reflecting the realized economic performance of intelligent manufacturing activities; $K_{i,t}$ represents intelligent manufacturing capital input, including both hardware capital (net book value of machinery and equipment, electronic devices, computers and auxiliary equipment, and communication equipment) and software capital (net book value of software assets reported under intangible assets); $L_{i,t}$ denotes intelligent manufacturing labor input, measured by the total number of production and technical employees; $v_{i,t}$ captures random statistical noise; $u_{i,t}$ represents technical inefficiency. Higher values indicates greater intelligent manufacturing efficiency and a higher level of intelligent manufacturing development. These input and output components are presented to indicate the methodological basis of the adopted PSFA based index and to clarify its theoretical suitability for capturing firm-level intelligent transformation.

The PSFA-based intelligent manufacturing index is adopted because it is consistent with the capability-oriented definition of intelligent manufacturing in this dissertation. Intelligent manufacturing is not treated simply as the possession of intelligent equipment, participation in pilot programs, or the disclosure of related keywords. Rather, it is understood as a firm-level transformation capability embedded in production organization, intelligent manufacturing related capital input, technical labor input, and operational conversion efficiency. The PSFA approach is therefore suitable because it measures the extent to which enterprises transform intelligent manufacturing related capital and labor inputs into realized economic output. In this sense, the index captures not only whether enterprises allocate resources to intelligent manufacturing, but also whether such resources are effectively converted into production outcomes.

The use of capital and labor inputs has a specific methodological meaning. Capital input reflects the material and digital infrastructure required for intelligent manufacturing, including machinery and equipment, electronic devices, computers and auxiliary equipment, communication equipment, and software assets. Labor input reflects the production and technical workforce needed to operate, maintain, and improve intelligent systems. These two dimensions represent the basic observable resource foundation of enterprise-level intelligent manufacturing and make the index suitable for large-sample firm-year panel analysis.

At the same time, the PSFA-based index should be interpreted as a capability-oriented proxy rather than a complete measure of all dimensions of intelligent manufacturing. Intelligent manufacturing also involves data architecture, algorithmic capability, platform integration, supply-chain connectivity, managerial coordination, and organizational learning, which cannot be fully captured by capital and labor inputs alone. In addition, operating revenue may also be affected by market demand, industry cycles, and firm strategy, rather than only by intelligent manufacturing efficiency. Therefore, the index has clear advantages in objectivity and comparability, but it also has measurement boundaries. To reduce reliance on a single measurement approach, this dissertation further employs a disclosure-based text measure of intelligent manufacturing as an alternative proxy in the robustness tests. The consistency of the results across different measures helps strengthen the credibility of the empirical findings.

Mediating Variables

To explore the internal mechanisms through which intelligent manufacturing affects enterprise ESG performance, this dissertation examines four mediating variables: information transparency, green innovation, financing constraints, and synergistic governance.

Information Transparency (TRANS)

Information transparency captures the quality, timeliness, and accessibility of enterprise-level information disclosed to external stakeholders. It reflects the extent to which enterprises reduce information asymmetry with investors, regulators, and the public. According to information asymmetry theory, higher transparency enhances external monitoring and governance efficiency, thereby influencing enterprises' ESG related behavior (Healy & Palepu, 2001; Bushman et al., 2004).

Following prior studies, information transparency is proxied using indicators related to information disclosure quality and analyst following, which are widely used to reflect enterprises' disclosure environment and information visibility in capital markets (Lang & Lundholm, 1996; Yu, 2008). Information transparency is defined as the natural logarithm of one plus the number of financial analysts issuing earnings forecasts for a firm in a given year (Lang & Lundholm, 1996; Yu, 2008; Healy et al., 2010). Higher TRANS values indicate greater transparency and lower information asymmetry, facilitating stakeholder supervision and ESG engagement.

TRANS is included as a mediating variable because information transparency represents one of the most direct channels through which intelligent manufacturing may influence ESG performance. According to Information Asymmetry Theory, higher transparency reduces uncertainty, improves disclosure credibility, and strengthens stakeholder monitoring. Intelligent manufacturing may enhance transparency by improving data collection, traceability, real-time monitoring, and the consistency of disclosure-related information. TRANS is therefore used to capture the informational transmission mechanism linking intelligent manufacturing to ESG outcomes.

Green Technological Innovation (GTI)

Green innovation measures enterprises' innovation activities aimed at environmental protection, energy efficiency improvement, and emission reduction. Green innovation is widely regarded as a key technological channel through which enterprises achieve sustainable development and improve ESG performance (Porter & van der Linde, 1995; Rennings, 2000).

Consistent with existing literature, green innovation is proxied by the number (or proportion) of green patent applications granted to a firm in a given year GTI (Popp, 2005; Cai & Li, 2018; Long et al., 2023). Specifically, green patents are identified based on the International Patent Classification (IPC) green technology list issued by the World Intellectual Property Organization (WIPO). Green patent data, obtained from the CSMAR Patent Database, capture enterprises' substantive technological efforts toward environmental sustainability and provide an objective measure of innovation outcomes related to ESG improvement. To mitigate skewness and scale effects, the variable is constructed as the natural logarithm of one plus the number of granted green patents.

GTI is selected as a mediating variable because green innovation constitutes an important pathway through which intelligent manufacturing may be translated into environmental and broader ESG improvement. Intelligent manufacturing can facilitate cleaner production, improve process control, optimize resource use, and support sustainability-oriented technological upgrading. From the Resource Based View, green technological innovation reflects the enterprise's ability to reconfigure technological and organizational resources in ways that generate sustainability-related value. GTI is therefore treated as the innovation-based channel through which intelligent manufacturing may improve ESG performance.

Financing Constraints (KZ)

Financing constraints reflect the degree of difficulty enterprises face in accessing external financial resources. Firms subject to tighter financing constraints are generally less capable of undertaking long-term investments with high uncertainty and delayed returns, such as ESG related projects in environmental protection, social responsibility, and governance improvement (Fazzari et al., 1988; Lamont et al., 2001).

Following the mainstream literature, this dissertation adopts the Kaplan-Zingales (KZ) index to measure firm-level financing constraints. The KZ index is a composite indicator constructed based on enterprises' cash flow, leverage, Tobin's Q, dividend payments, and cash holdings, and has been widely used to capture external financing frictions in corporate finance research (Kaplan & Zingales, 1997; Lamont et al., 2001; Hadlock & Pierce, 2010).

Compared with single-indicator measures, the KZ index provides a more comprehensive assessment of enterprises' financing conditions by incorporating both internal financial capacity and external financing pressure. Firm-level financial data required to construct the KZ index are obtained from the CSMAR Financial Statements Database and supplemented by the WIND database where necessary.

A higher value of the KZ index indicates more severe financing constraints. This variable captures the resource availability mechanism through which intelligent manufacturing may influence enterprise ESG performance: by improving operational efficiency, information transparency, and risk profiles, intelligent manufacturing can alleviate financing constraints, thereby enhancing enterprises' capacity to sustain ESG related investments.

KZ is included as a mediating variable because the financial implications of intelligent manufacturing are central to the enterprise's capacity to sustain ESG related investment. Intelligent transformation often requires substantial upfront expenditure and continued capital input, which means that financing conditions may either facilitate or constrain the realization of ESG gains. At the same time, intelligent manufacturing may alter external financing conditions by improving operational credibility, information quality, and growth expectations. KZ is therefore theoretically relevant as a proxy for the financial channel through which intelligent manufacturing may affect enterprise ESG performance.

Synergistic Governance (DEM)

Synergistic governance refers to enterprises' ability to coordinate internal departments and external stakeholders through integrated governance structures, digital platforms, and data-driven management systems. Stakeholder theory emphasizes that effective ESG performance relies on coordinated actions among multiple actors rather than isolated managerial decisions (Freeman, 1984; Aguilera et al., 2007). In the context of digital transformation, digital empowerment of governance has become a key foundation for achieving governance synergy. Intelligent manufacturing enables enterprises to integrate production systems, management platforms, and governance processes through digital technologies, thereby enhancing cross-departmental coordination, real-time monitoring, and collaborative decision-making.

Consistent with recent studies on digital governance and organizational coordination, this dissertation measures synergistic governance using the Digital Empowerment of Management (DEM) index, which captures the extent to which digital technologies are embedded in enterprises' management and governance processes (Chen et al., 2020; Li et al., 2022). The DEM index reflects enterprises' capabilities in digital management integration, information sharing, and organizational coordination, all of which are essential for synergistic ESG governance. The governance coordination capacity emphasized in this dissertation becomes empirically observable mainly through the extent to which digital technologies are embedded in management processes, information sharing, cross-functional coordination, and collaborative decision-making. Accordingly, DEM index is treated as a proxy for the digitally enabled coordination capacity through which intelligent manufacturing may affect enterprise ESG performance.

Synergistic governance is measured by the Digital Empowerment of Management index (DEM). In this dissertation, DEM is directly obtained from the relevant database as a standardized firm-year indicator. It reflects the extent to which digital technologies are embedded in enterprises' management and governance processes, including information integration, process coordination, data-based decision-making, intelligent office and operation platforms, and digital governance support.

A higher DEM value indicates a higher degree of digital empowerment in management and stronger digitally enabled coordination capacity. Since synergistic governance is not directly observable as a single organizational outcome, DEM is used as a proxy for the enterprise's ability to integrate information flows, coordinate internal departments, monitor operational processes, and support cross-functional governance. In this sense, DEM is consistent with the theoretical logic of synergistic governance in this dissertation. A detailed measurement note and standardized-index representation are provided in Appendix 15A.

DEM is included as a mediating variable because intelligent manufacturing affects not only production efficiency but also internal coordination, cross-functional integration, and broader governance processes. From the perspectives of Stakeholder Theory and organizational coordination logic, intelligent manufacturing may improve ESG performance by enhancing the enterprise's capacity to coordinate production, environmental management, information flows, and stakeholder-related responses across departments and along the supply chain. DEM is therefore used to capture the governance and coordination pathway through which intelligent manufacturing may influence ESG performance.

Control Variables

To mitigate potential omitted-variable bias and isolate the effect of intelligent manufacturing on enterprise ESG performance, this dissertation incorporates a set of firm-level control variables that are widely used in the ESG and corporate governance literature. These variables capture firms' size, financial structure, profitability, ownership concentration, organizational maturity, and ownership nature.

Firm Size (SIZE)

Firm size reflects the overall scale of an enterprise's operations and resource endowment. Larger enterprises generally possess more financial and organizational resources and face stronger public scrutiny, which may influence ESG engagement. Following prior studies, firm size is measured as the natural logarithm of total assets at the end of the fiscal year (Brammer & Pavelin, 2006; Eccles et al., 2014; Li et al., 2023) . Firm size data can be obtained from the CSMAR Financial Statements Database and cross-checked with WIND.

SIZE is included as a control variable because larger enterprises typically possess stronger resource endowments, more developed governance systems, and greater access to technology, financing, and professional services. These characteristics may influence both the extent of intelligent-manufacturing transformation and the level of ESG performance. Controlling for firm size is therefore necessary to distinguish the effect of intelligent manufacturing from broader scale-related advantages.

Leverage (LEV)

Leverage captures enterprises' capital structure and financial risk exposure. Highly leveraged enterprises may face tighter financial constraints, potentially limiting ESG related investments. Leverage is measured as the ratio of total liabilities to total assets (Cheng et al., 2014; Velte, 2017; Nirino et al., 2021). Financial data are sourced from the CSMAR Financial Statements Database.

LEV is controlled for because capital structure may affect both intelligent-manufacturing decisions and ESG performance. Enterprises with higher leverage may face tighter financing pressure and stronger short-term repayment obligations, which can constrain investment in digital upgrading and sustainability-related activities. At the same time, leverage may influence external monitoring and risk exposure. LEV is therefore theoretically important for accounting for the financial structure within which intelligent-manufacturing and ESG choices are made.

Profitability (ROA)

Profitability reflects enterprises' internal cash-generating capacity, which affects their ability to invest in ESG activities. Return on assets (ROA) is calculated as net income divided by total assets (Waddock & Graves, 1997; Abdi et al., 2022; Du & Kong, 2024. Financial statement data are obtained from CSMAR and WIND.

ROA is included because profitability reflects the enterprise's internal cash-generating capacity and resource availability. More profitable enterprises are generally better positioned to finance intelligent transformation, absorb adjustment costs, and sustain ESG related investment. Controlling for profitability is therefore necessary to separate the effect of intelligent manufacturing from the enterprise's underlying financial strength.

Ownership Concentration (TOP1)

Ownership concentration reflects the degree of control exerted by the largest shareholder. Concentrated ownership may affect ESG decisions through monitoring incentives or expropriation risks. Following the literature, TOP1 is measured as the shareholding ratio of the top 1 largest shareholder (La Porta et al., 1999; Tan & Liu, 2024; Wu et al., 2022). Ownership data are sourced from the CSMAR Ownership Structure Database.

TOP1 is controlled for because ownership concentration may shape managerial incentives, monitoring intensity, and strategic priorities. Since intelligent manufacturing and ESG performance are both affected by internal governance arrangements, ownership concentration is theoretically relevant as a control for the enterprise's governance structure.

Firm Age (Age)

Firm age captures organizational maturity and accumulated experience. Older firms may have more stable governance structures but may also exhibit organizational inertia. Firm age is measured as the number of years since the firm's listing year (Coad et al., 2016; Zhang &

Zhao, 2019; Shi et al., 2025). Listing information is obtained from the CSMAR Listed Firms Database.

Age is included because organizational maturity may influence both digital transformation capacity and ESG performance. Older enterprises may benefit from accumulated experience and legitimacy, but they may also face greater organizational inertia and legacy-system constraints. Firm age is therefore controlled for in order to account for life-cycle differences that may affect both the adoption and the effectiveness of intelligent manufacturing.

State Ownership (SOE)

State ownership reflects the nature of enterprise ownership and political affiliation. State-owned enterprises (SOEs) often face stronger policy pressure and social responsibility requirements. SOE is measured as a dummy variable, taking the value of 1 if the enterprise is state-owned and 0 otherwise (Li et al., 2018; Wang et al., 2022; Xue et al., 2022). Ownership type data are obtained from the CSMAR Corporate Governance Database.

SOE is included because ownership type is especially important in the Chinese institutional context. State-owned enterprises often face stronger policy guidance, different resource access conditions, and greater public expectations than non-state-owned firms. These differences may affect both the implementation of intelligent manufacturing and the pursuit of ESG objectives. Controlling for SOE status is therefore theoretically justified because it captures an institutional characteristic that may shape enterprises' strategic behavior and sustainability performance.

Adequacy and Rationality of Control Variables

The selected control variables are both sufficient and methodologically appropriate for the research context of this dissertation for the following reasons.

First, the control variables comprehensively capture key enterprise-level characteristics that may simultaneously affect intelligent manufacturing adoption and enterprise ESG performance, including scale effects (SIZE), financial capacity (ROA, LEV), governance structure (TOP1), organizational maturity (Age), and institutional ownership background (SOE).

Second, these variables are widely adopted in high-quality ESG and corporate governance studies, ensuring comparability with existing literature and enhancing external validity.

Third, the exclusion of additional controls, such as market competition, pollution intensity, or industry-specific risk, is theoretically justified and empirically addressed through the inclusion of industry fixed effects and year fixed effects, which effectively absorb time-invariant industry characteristics and macroeconomic shocks.

Overall, the chosen control variables strike an appropriate balance between model parsimony and explanatory power, reducing multicollinearity risks while ensuring robust estimation of the core relationships examined in this dissertation.

The detailed definitions and descriptions of these variables are presented in Table 2.2.

Table 2.2 Variable Definitions and Descriptions

Source: Developed by the author

Type	Variable	Name	Calculation/Value
Dependent Variable	ESG	Enterprise ESG Performance	Huazheng ESG rating converted into numerical scores from 9 (AAA) to 1 (C); higher values indicate better enterprise ESG performance
Independent Variable	IM	Intelligent Manufacturing Level	Firm-level intelligent manufacturing index constructed using panel stochastic frontier analysis (PSFA); higher values indicate higher intelligent manufacturing efficiency
Mediating Variables	TRANS	Information Transparency	ln(1+number of financial analysts covering the firm in a given year)
	GTI	Green Technology Innovation	ln(1+number of granted green patent applications identified by WIPO IPC green classification)
	KZ	Financing Constraints	Kaplan-Zingales (KZ) index constructed using cash flow, leverage, Tobin's Q, dividends, and cash holdings; higher values indicate tighter constraints
	DEM	Synergistic Governance	Digital Empowerment of Management (DEM) index capturing digital integration of management and governance processes
Control Variables	SIZE	Firm size	Natural logarithm of total assets
	LEV	Financial leverage	Total liabilities divided by total assets
	ROA	Profitability	Net income divided by total assets
	TOP1	Ownership concentration	Shareholding ratio of the top 1 largest shareholder
	Age	Firm age	Number of years since firm listing
	SOE	State ownership	Dummy variable equal to 1 if the firm is state-owned, and 0 otherwise
	Year	Year fix	Year dummy variable
	Firm	Firm fix	Firm dummy variable

Notes: All variables are constructed at the firm-year level. Continuous variables are winsorized at the 1st and 99th percentiles.

Alternative variables for robustness checks

The inclusion of ESG2 and IM2 in robustness analysis is also theoretically meaningful. ESG2 provides an alternative measure of the dependent variable using WIND ESG Rating, allowing the study to test whether the observed relationship is sensitive to a specific ESG rating system. IM2 provides a disclosure-based proxy for intelligent manufacturing, reflecting enterprise's strategic emphasis and reporting intensity with respect to intelligent transformation. Although these alternative indicators differ from the baseline measures, they remain conceptually aligned with the dissertation's broader understanding of ESG performance and intelligent manufacturing.

Overall, the variable system adopted in this dissertation is theoretically structured rather than mechanically assembled. The dependent variable corresponds to the sustainability outcome of interest, the explanatory variable captures the core organizational capability under investigation, the mediating variables operationalize the principal transmission channels proposed by the theoretical framework, and the control variables account for competing firm-level explanations related to resources, governance, financial condition, and institutional attributes. This structure provides the necessary foundation for deriving the subsequent econometric models from the dissertation's theoretical framework.

2.2.3 Econometric Model Specification

To examine the impact of intelligent manufacturing on enterprise ESG performance, this dissertation constructs a set of firm-year panel regression models derived from the theoretical framework established in the preceding sections. The purpose of the baseline econometric specification is not simply to identify whether intelligent manufacturing and ESG performance are statistically associated, but to test the core theoretical proposition that intelligent manufacturing, understood as a firm-level organizational capability, contributes to broader sustainability-oriented corporate outcomes. In this sense, the baseline model constitutes the empirical expression of Hypothesis H1.

The specification of the baseline equation follows directly from the structure of the theoretical framework and the variable system introduced in Section 2.2.2. Enterprise ESG performance is used as the dependent variable because it captures the multidimensional sustainability outcome that this dissertation seeks to explain. Intelligent manufacturing is used as the core explanatory variable because, in line with the Resource Based View, it represents the key organizational capability under investigation. The control variables are incorporated because firm size, capital structure, profitability, ownership concentration, organizational maturity, and ownership type may simultaneously affect both intelligent-manufacturing development and ESG performance. Their inclusion is therefore theoretically necessary to reduce the risk that the estimated effect of intelligent manufacturing is confounded by other firm-level characteristics.

Because the dataset has a panel structure, the econometric design must also account for unobserved heterogeneity across firms and over time. Firms may differ in relatively persistent but difficult-to-measure attributes, such as managerial philosophy, organizational culture, production tradition, or governance orientation, all of which may influence both intelligent-manufacturing decisions and ESG performance. At the same time, firms are jointly exposed to year-specific shocks, including macroeconomic fluctuations, regulatory changes, industrial policies, and evolving ESG related disclosure requirements. For this reason, the baseline model adopts a two-way fixed-effects specification, which makes it possible to estimate the within-firm relationship between changes in intelligent manufacturing and changes in ESG performance while controlling for unobserved time-invariant enterprise heterogeneity and common year-specific shocks.

To test Hypothesis H1, which posits that intelligent manufacturing positively affects enterprise ESG performance, the following baseline model is specified:

$$\text{ESG}_{i,t} = \alpha_0 + \alpha_1 IM_{i,t} + \sum_{\text{j}} \alpha_2 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (2.3)$$

Where $\text{ESG}_{i,t}$ denotes the enterprise ESG performance of firm *i* in year *t*, measured by the Huangzheng ESG score; $IM_{i,t}$ represents the level of intelligent manufacturing and serves as the core explanatory variable; $Control_{j,i,t}$ is a vector of enterprise-level control variables; μ_i captures firm fixed effects; λ_i denotes year fixed effects; and $\epsilon_{i,t}$ is the idiosyncratic error term.

The choice of the fixed-effects estimator is supported not only by the theoretical structure of the research question, but also by the statistical properties of the data. A Hausman specification test is conducted to determine the appropriate estimation method. The test results strongly reject the null hypothesis of random effects (p-value = 0.000), indicating that a fixed-effects estimator is more suitable. Accordingly, a two-way fixed-effects model is employed. Firm fixed effects control for time-invariant characteristics such as industry attributes, corporate culture, and managerial style, while year fixed effects account for macroeconomic shocks and policy changes that affect all enterprises simultaneously. This approach ensures that the estimated relationship between intelligent manufacturing and enterprise ESG performance is not biased by unobservable firm-specific or temporal factors.

The baseline model does not separately include macroeconomic indicators as control variables. Common macroeconomic shocks, such as national economic cycles, regulatory changes, capital-market conditions, and broad sustainability-policy shocks, are controlled through year fixed effects. Firm fixed effects further absorb time-invariant firm characteristics and relatively stable regional and institutional conditions. Since this dissertation focuses on firm-level mechanisms linking intelligent manufacturing to ESG performance, the control variables are mainly selected to capture firm financial capacity, governance structure, organizational maturity, and ownership background. Province-level macroeconomic variables are not mechanically added because they may overlap with year effects and local policy environments, which may create multicollinearity or over-control concerns. Therefore, macroeconomic influences are addressed mainly through fixed effects, while contextual differences are further examined through heterogeneity analysis.

A significantly positive coefficient on $IM_{i,t}$ ($\alpha_1 > 0$) provides empirical support for Hypothesis H1. More importantly, the baseline model serves as the analytical point of departure for the subsequent mediation and heterogeneity analyses. It establishes the total effect of intelligent manufacturing on enterprise ESG performance before the dissertation proceeds to examine the organizational channels through which that effect is transmitted and the institutional conditions under which it varies.

Potential endogeneity is also considered in the empirical design. Although the baseline fixed-effects model controls for unobserved firm heterogeneity and common year shocks, reverse causality may still exist. Firms with better ESG performance may have stronger resources, more formalized governance systems, and greater external recognition, which may increase their ability to adopt intelligent manufacturing. In addition, ESG performance is likely to be dynamically persistent, because environmental management, social responsibility practices, governance quality, and disclosure systems usually accumulate over time. Therefore, this dissertation does not rely only on the baseline fixed-effects model. It further uses PSM-DID, System GMM estimation, and dynamic lagged-effect tests as complementary analyses to examine whether the main conclusion remains stable after considering selection bias, reverse causality, and intertemporal persistence.

2.2.4 Mediation Effect Model Design

To further investigate the internal mechanisms through which intelligent manufacturing influences enterprise ESG performance, mediation effect models are constructed to test Hypotheses H2-H5. Its purpose is to translate the mechanism hypotheses developed in Chapter 1 into estimable empirical models and thereby examine whether intelligent manufacturing influences ESG performance through identifiable organizational channels.

The selection of the mediating variables follows directly from the theoretical framework. Information transparency represents the informational channel emphasized by Information Asymmetry Theory, because intelligent manufacturing may improve data visibility, traceability, and disclosure credibility, thereby reshaping the informational environment in which ESG performance is evaluated. Green technological innovation represents the innovation channel, because intelligent manufacturing may support cleaner production, technological upgrading, and sustainability-oriented innovation. Financing constraints represent the financial channel, because intelligent transformation both depends on and potentially reshapes enterprises' financing conditions, which in turn affect their ability to sustain ESG related investment. Synergistic governance represents the organizational coordination channel and is operationalized by DEM, which captures management related digital empowerment at the firm level, because intelligent manufacturing may improve cross-functional integration, management digitalization, and governance responsiveness, all of which are relevant to enterprise ESG performance. Following the stepwise regression approach proposed by Wen and Ye (2014), the mediation analysis is conducted using the following equations.

First, the effect of intelligent manufacturing on the mediating variable is estimated:

$$\mathrm{M}_{i,t} = \beta_0 + \beta_1 IM_{i,t} + \sum_{\mathrm{j}} \beta_2 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (2.4)$$

Where $\mathrm{M}_{i,t}$ denotes the mediating variable for firm i in year t. In this study, the mediators include information transparency (TRANS), green technological innovation (GTI), financing constraints (KZ), and synergistic governance (DEM), each representing a distinct transmission channel through which intelligent manufacturing may affect enterprise ESG performance.

Second, both intelligent manufacturing and the mediating variable are included in the enterprise ESG performance equation:

$$\mathrm{ESG}_{i,t} = \gamma_0 + \gamma_1 IM_{i,t} + \gamma_2 \mathrm{M}_{i,t} + \sum_{\mathrm{j}} \gamma_3 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (2.5)$$

If β_1 and γ_2 are both statistically significant and the absolute value of γ_1 is smaller than that of α_1 in the baseline model 2.3, a partial mediation effect is confirmed. If γ_1 becomes statistically insignificant after the inclusion of the mediator, a full mediation effect is indicated.

This modeling framework allows for a systematic decomposition of the total effect of intelligent manufacturing on enterprise ESG performance into direct and indirect components, thereby providing empirical evidence for the proposed mechanism hypotheses.

Through the combination of the baseline model and mediation effect models, this dissertation comprehensively examines: the direct impact of intelligent manufacturing on corporate ESG performance (H1); the indirect effects operating through information transparency (H2), green technological innovation (H3), financing constraints (H4), and synergistic governance (H5); the role of enterprise-level controls and unobservable heterogeneity in shaping ESG outcomes.

The mediation models retain the same core specification logic as the baseline model. The same set of control variables is included to account for alternative firm-level influences, and the same fixed-effects structure is retained to ensure comparability across model stages. This consistency is important because the mediation analysis is not designed as a separate empirical exercise, but as an extension of the baseline model within the same theory-driven research design. In addition, all regressions are estimated using firm-clustered robust standard errors to address potential heteroskedasticity and serial correlation in the panel data.

Accordingly, the mediation-effect model design provides a direct empirical bridge between theoretical mechanism analysis and econometric testing. Rather than treating the proposed channels as descriptive interpretations added after the regressions, this design allows the dissertation to examine whether information transparency, green technological innovation, financing constraints, and synergistic governance function as the principal transmission processes through which intelligent manufacturing affects enterprise ESG performance.

2.2.5 Heterogeneity Analysis Model Construction

To further explore whether the impact of intelligent manufacturing on enterprise ESG performance varies across different institutional and firm-specific contexts, this dissertation conducts a series of heterogeneity analyses. Drawing on Institutional Theory, which emphasizes the role of external institutional environments and organizational attributes in shaping corporate behavior, heterogeneity is examined along three dimensions: regional development differences, technological attributes, and listing-board characteristics. These three dimensions are selected because they capture different combinations of institutional pressure, market discipline, and firm-level capability, all of which may condition whether intelligent manufacturing can be translated into observable ESG gains.

In methodological terms, the heterogeneity analysis is implemented by dividing the full sample into theoretically meaningful sub-samples and then re-estimating the baseline model for each group. This approach is appropriate because the dissertation is not attempting to identify a fundamentally different causal structure for each subgroup, but to test whether the magnitude and statistical significance of the relationship between intelligent manufacturing and enterprise ESG performance differ under different contextual conditions. For this reason, Equation 2.3 is retained as the common empirical specification, while the sample composition is varied according to the heterogeneity dimension under consideration.

Regional Heterogeneity

Regional heterogeneity is examined because the ESG implications of intelligent manufacturing depend not only on firm-level technological upgrading, but also on the broader regional environment in which that upgrading occurs. Differences in industrial supporting conditions, digital infrastructure, market development, regulatory quality, and institutional pressure may influence whether intelligent-manufacturing capability can be effectively translated into observable ESG gains.

To examine whether regional context moderates the relationship between intelligent manufacturing and enterprise ESG performance, the full sample is divided into Western and non-Western regions according to the official regional classification standard of the National Bureau of Statistics of China. This grouping is adopted because regional differences in industrial supporting conditions, digital infrastructure, market development, and institutional quality may affect not only the implementation of intelligent manufacturing, but also the extent to which such transformation can be translated into ESG related outcomes. The baseline model 2.3 is then estimated separately for the two sub-samples:

$$\mathrm{ESG}_{i,t} = \alpha_0 + \alpha_1 IM_{i,t} + \sum_{\mathrm{j}} \alpha_2 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (2.3)$$

Differences in the estimated coefficients of $IM_{i,t}$ across the two sub-samples indicate whether regional context conditions the effect of intelligent manufacturing on enterprise ESG performance. A larger and more significant coefficient in the non-Western sub-sample would provide empirical support for Hypothesis H6.

Technological Attributes Heterogeneity

Firms differ substantially in their technological endowments, innovation capabilities, and absorptive capacity, which may condition how effectively intelligent manufacturing translates into enterprise ESG performance. According to Resource-Based View, enterprises with stronger technological foundations are better positioned to integrate intelligent manufacturing technologies into production processes, innovation activities, and governance practices, thereby generating more pronounced sustainability outcomes.

In the Chinese context, high-tech enterprises are officially certified based on criteria such as R&D intensity, technological sophistication, and innovation output. These enterprises typically possess stronger digital capabilities, more advanced human capital, and greater experience in technology-driven transformation. As a result, intelligent manufacturing is more likely to enhance ESG performance among high-tech enterprises by facilitating green innovation, improving resource efficiency, and strengthening governance mechanisms.

To examine heterogeneity arising from technological attributes, the full sample is divided into high-tech enterprises and non-high-tech enterprises according to official certification standards. The baseline model 2.3 is then estimated separately for each sub-sample:

$$\text{ESG}_{i,t} = \alpha_0 + \alpha_1 IM_{i,t} + \sum_{\text{j}} \alpha_2 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (2.3)$$

Differences in the estimated coefficient of $IM_{i,t}$ across the two sub-samples indicate whether enterprises' technological attributes moderate the relationship between intelligent manufacturing and enterprise ESG performance. A larger and more significant coefficient for high-tech enterprises would suggest that superior technological capabilities amplify the ESG enhancing effects of intelligent manufacturing, thereby providing empirical support for Hypothesis H7.

Listing Board Heterogeneity

China's multi-tier capital market system is characterized by differences in listing requirements, information disclosure standards, investor composition, and regulatory intensity across boards. Firms listed on the Shanghai and Shenzhen main boards typically face more stringent governance and disclosure requirements than those listed on the Beijing Stock Exchange, which primarily serves innovative small and medium-sized enterprises.

To examine whether capital market segmentation moderates the impact of intelligent manufacturing on enterprise ESG performance, the sample is divided according to listing board, and the baseline model 2.3 is estimated separately:

$$\text{ESG}_{i,t} = \alpha_0 + \alpha_1 IM_{i,t} + \sum_{\text{j}} \alpha_2 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (2.3)$$

Significant differences in the coefficient of across listing boards would indicate that capital market institutions shape enterprises' ability to convert intelligent manufacturing investments into enterprise ESG performance improvements. A stronger effect among Shanghai and Shenzhen listed companies would provide support for Hypothesis H8.

By conducting subgroup regressions across regions, technological attributes, and listing boards, this dissertation systematically examines how institutional environments and firm attributes moderate the relationship between intelligent manufacturing and enterprise ESG performance. This heterogeneity analysis not only enhances the robustness of the baseline findings but also deepens the understanding of when and for whom intelligent manufacturing is most effective in promoting corporate sustainability.

2.2.6 Data Processing and Software Tools

All quantitative analyses are conducted using standard econometric software STATA. Fixed effects regressions, mediation effect tests, and robustness checks are implemented using appropriate statistical commands. Robust standard errors are applied to address potential heteroskedasticity and serial correlation issues. The combination of rigorous data processing procedures and transparent analytical tools enhances the reliability and replicability of the empirical results.

2.2.7 Quantitative Research Summary

Overall, the quantitative research design of this dissertation provides a rigorous and systematic framework for testing the theoretical propositions regarding intelligent manufacturing and enterprise ESG performance. By combining baseline estimations with mediation analysis and heterogeneity tests, the empirical strategy not only evaluates whether intelligent manufacturing enhances enterprise ESG performance, but also elucidates how and under what conditions such effects materialize. The use of multiple mediating variables allows for a nuanced understanding of the resource, information, innovation, and governance channels through which intelligent manufacturing influences sustainable development outcomes.

Moreover, the adoption of panel data techniques and comprehensive robustness considerations enhances the reliability and generalizability of the findings. Through this quantitative approach, the dissertation generates solid empirical evidence to support the theoretical arguments and offers policy-relevant insights for promoting the coordinated development of intelligent manufacturing and ESG practices. The results of the quantitative analysis serve as the empirical foundation for subsequent discussions and interpretations, contributing to a deeper understanding of the role of intelligent manufacturing in shaping enterprises' sustainable development trajectories.

2.3 Qualitative Research

While the quantitative analysis provides large-sample statistical evidence on the relationship between intelligent manufacturing and corporate ESG performance, it is inherently limited in capturing firm-specific implementation processes and contextual mechanisms. In particular, econometric models are less effective in illustrating how intelligent manufacturing initiatives are operationalized within organizations, how they interact with governance structures, and how different mechanism channels unfold in practice. To address these limitations and to enhance the explanatory power of the empirical findings, this dissertation adopts a qualitative case study approach as an essential complementary research method.

2.3.1 Role of Qualitative Research in the Mixed-Methods Design

The qualitative research component serves three primary purposes:

First, it provides mechanism validation, offering process-level evidence for the mediating pathways identified in the quantitative analysis, including information transparency, green innovation, financing constraints, and synergistic governance.

Second, it facilitates contextual interpretation, allowing the study to capture organizational, technological, and institutional factors that are difficult to quantify but critical to ESG outcomes.

Third, it enhances external credibility and practical relevance by translating statistical relationships into concrete managerial practices and policy-relevant insights.

Rather than serving as an independent empirical test, the case study method is embedded within the overall mixed-methods research design and is explicitly aligned with the hypotheses developed in Chapter 1. In this sense, qualitative analysis functions as a mechanism-oriented and explanatory extension of the quantitative results.

2.3.2 Case Selection Strategy

The case-study component of this dissertation follows a logic of theoretical sampling rather than statistical sampling. The purpose of the qualitative analysis is not to derive population-level inference from a small number of enterprises, but to identify information-rich cases that make it possible to examine the organizational processes through which intelligent manufacturing may influence enterprise ESG performance. In this sense, case selection is guided primarily by explanatory relevance rather than numerical representativeness.

Two considerations are particularly important in this regard. First, the selected cases must allow the core mechanisms identified in the quantitative analysis to be observed in relatively concrete organizational settings. Since the qualitative component is designed to complement regression-based evidence, the value of the cases lies in their ability to reveal how the relationship under examination is enacted in practice, rather than merely to restate the statistical findings in narrative form. Second, the cases must provide sufficiently reliable and traceable evidence to support process-oriented interpretation. This requires that the enterprises under consideration possess relatively clear intelligent-manufacturing trajectories and adequate documentary materials, so that the analysis can be grounded in verifiable organizational evidence rather than impressionistic description.

Accordingly, the case-selection strategy in this dissertation is best understood as an effort to maximize analytical leverage under a mixed-methods design. The cases are chosen because they are capable of illuminating different aspects of the mechanism structure identified in the econometric analysis, while also helping to bridge the gap between statistical regularities and firm-level organizational dynamics. The specific enterprises selected on this basis are introduced in the empirical chapter, where the logic of case matching is discussed in relation to the four mechanism channels examined in the dissertation

2.3.3 Data Sources and Analytical Approach

The qualitative analysis relies exclusively on publicly available and authoritative data sources, including corporate annual reports, ESG and sustainability reports, official corporate disclosures, policy documents, and credible media coverage. This approach ensures data reliability and replicability while avoiding subjective bias.

A structured content analysis method is employed to systematically extract evidence related to intelligent manufacturing practices and ESG related outcomes. Particular attention is paid to how intelligent manufacturing reshapes firms' information systems, innovation processes, financial conditions, and governance coordination, as well as how these changes contribute to improvements in environmental performance, social responsibility, and governance quality.

2.3.4 Mechanism-Oriented Case Mapping

Each case is explicitly linked to one mediating mechanism identified in the quantitative analysis.

The Haier Smart Home case focuses on how industrial internet platforms enhance information transparency and reduce information asymmetry, providing qualitative support for Hypothesis H2.

The Midea Group case illustrates how intelligent manufacturing enables green design, energy efficiency improvement, and circular economy practices, supporting Hypothesis H3.

The CATL case demonstrates how intelligent manufacturing improves operational stability and financial resilience, thereby easing financing constraints and supporting Hypothesis H4.

The Seres case highlights how digital platforms facilitate cross-organizational coordination and lifecycle carbon management, offering qualitative evidence for Hypothesis H5.

Through this mechanism-specific mapping, the qualitative analysis directly complements the mediation models tested in the quantitative section.

2.3.5 Contribution of Qualitative Analysis

Overall, the qualitative research component strengthens the internal coherence of the dissertation by bridging theoretical reasoning, econometric evidence, and real-world corporate practices. By revealing how intelligent manufacturing operates within firms and how ESG improvements materialize through distinct channels, the case studies enhance confidence in the causal interpretations derived from the quantitative analysis.

Together with the large-sample empirical results, the qualitative findings contribute to a more comprehensive understanding of intelligent manufacturing as a multidimensional driver of corporate ESG performance, thereby reinforcing the robustness and practical relevance of the study's conclusions.

2.4 Summary of the Chapter

In summary, this chapter has presented the overall research framework and methodological design adopted in this dissertation. By integrating panel data econometric analysis with mediation and heterogeneity tests, and supplementing the quantitative findings with representative case studies, this research design enables a comprehensive and robust examination of the relationship between intelligent manufacturing and enterprise ESG performance. The methodological choices are closely aligned with the research questions, hypotheses, and theoretical foundations established in the preceding chapters. On this basis, the next chapter proceeds to present the empirical results and analytical findings derived from the specified models and data, and to discuss their theoretical and practical implications.

CHAPTER 3. RESULTS AND ANALYSIS

3.1 Descriptive Statistics and Preliminary Analysis

3.1.1 Descriptive Statistics

Table 3.1 reports the descriptive statistics of the main variables used in this study. The sample consists of 30,730 firm-year observations of Chinese A-share listed companies over the period 2015-2023, providing a sufficiently large and representative data set for panel data analysis.

The average ESG score is 4.238, with a standard deviation of 0.959, and values ranging from 1 to 8. This indicates substantial variation in ESG performance across enterprises, suggesting that enterprises differ markedly in their environmental, social, and governance practices. Such variation provides an appropriate empirical basis for examining the determinants of ESG performance. The wide dispersion of ESG scores also implies that improvements in ESG performance are not uniform across enterprises, which is consistent with the dissertation's focus on heterogeneity analysis.

Regarding intelligent manufacturing, the mean value of the intelligent manufacturing index (IM) is 0.0176, with a standard deviation of 0.0250. The minimum value is close to zero, while the maximum reaches 0.402, indicating significant disparities in the level of intelligent manufacturing adoption among sample enterprises. This distribution reflects the uneven progress of intelligent manufacturing transformation in China, where a small number of enterprises have achieved relatively advanced intelligent manufacturing capabilities, while many enterprises remain at an early stage. Such heterogeneity supports the necessity of examining both the average effect and differentiated impacts of intelligent manufacturing on enterprise ESG performance.

With respect to enterprise characteristics, the average firm size (SIZE), measured as the natural logarithm of total assets, is 22.28, with a moderate standard deviation of 1.322, suggesting noticeable but not excessive differences in firm scale. The mean leverage ratio (LEV) is 0.406, indicating that, on average, liabilities account for approximately 40% of total assets, which is consistent with the capital structure of Chinese listed firms. Profitability, measured by return on assets (ROA), has a mean of 0.0344 but exhibits a relatively large dispersion, with values ranging from -1.856 to 0.786, reflecting substantial differences in enterprises' operating performance.

Ownership structure variables also display meaningful variation. The average shareholding ratio of the top1 largest shareholder (Top1) is 0.332, indicating a relatively concentrated ownership structure, which is a common characteristic of Chinese listed companies. Firm age (Age), expressed in logarithmic form, has a mean of 3.011, suggesting that the sample mainly consists of mature enterprises, while still retaining variation in firm life-cycle stages. Approximately 29.5% of the sample firms are state-owned enterprises (SOE), indicating meaningful variation in ownership characteristics across the sample. This variation is important because state ownership may shape firms' governance orientation, policy exposure, and ESG related incentives, and is therefore retained as an important control dimension in the subsequent regressions.

Regarding mechanism-related variables, green technological innovation (GTI) shows a low average value but substantial dispersion, implying that while many enterprises engage in limited green innovation activities, a subset of enterprises demonstrates relatively intensive green innovation efforts. Financing constraints, measured by the KZ index, have a mean of 1.071 and a wide range, suggesting pronounced differences in enterprises' access to external financing. The synergistic governance variable (DEM) has a small mean value but non-negligible variation, indicating heterogeneity in enterprises' governance coordination capacity.

In addition, alternative measures of ESG performance (ESG2) and intelligent manufacturing (IM2) exhibit wide ranges and substantial dispersion, supporting their suitability for robustness checks in subsequent empirical analysis. Overall, the descriptive statistics indicate that the sample variables display sufficient variability and reasonable distributions, providing a solid foundation for the econometric analyses conducted in the following sections.

Table 3.1 The descriptive of variables

Variable	Obs	Mean	SD	Min	Max
ESG	30,730	4.238	0.959	1	8
IM	30,730	0.0176	0.0250	0.000868	0.402
SIZE	30,730	22.28	1.322	17.64	28.70
LEV	30,730	0.406	0.201	0.00836	0.998
ROA	30,730	0.0344	0.0787	-1.856	0.786
Top1	30,730	0.332	0.148	0.00286	0.900
Age	30,730	3.011	0.306	1.386	4.304
SOE	30,730	0.295	0.456	0	1
TRANS	30,730	0.14844	0.163	0	3.07
GTI	30,730	0.0970	0.492	0	6.603
KZ	30,730	1.071	2.450	-12.89	11.52
DEM	30,730	0.00117	0.0677	-0.446	0.440
ESG2	30,730	1.620	2.516	0	9
IM2	30,730	7.064	27.63	0	856

Source: Developed by the author

3.1.2 Correlation Analysis and Multicollinearity Test

Table 3.2 presents the Pearson correlation coefficients among the main variables. The results show that intelligent manufacturing is positively and significantly correlated with enterprise ESG performance, providing preliminary evidence of a potential association between the two variables. However, the magnitude of the correlation is relatively small, indicating that intelligent manufacturing captures information beyond simple linear correlation and underscoring the necessity of multivariate regression analysis.

The correlations between ESG performance and control variables are generally consistent with theoretical expectations. ESG performance is positively associated with firm size, profitability, ownership concentration, and state ownership, while it is negatively correlated with leverage and firm age. These patterns suggest that firms with stronger financial capacity, better governance structures, and state ownership tend to exhibit higher ESG performance, whereas highly leveraged and older firms may face constraints in ESG engagement.

Table 3.2 Pearson Correlation Matrix of Main Variables

	ESG	IM	SIZE	LEV	ROA	Top1	Age	SOE
ESG	1							
IM	0.057***	1						
SIZE	0.199***	-0.062***	1					
LEV	-0.100***	-0.041***	0.499***	1				
ROA	0.187***	-0.084***	0.032***	-0.304***	1			
Top1	0.095***	-0.112***	0.168***	0.019***	0.155***	1		
Age	-0.035***	-0.051***	0.191***	0.190***	-0.074***	-0.048***	1	
SOE	0.046***	-0.058***	0.374***	0.267***	-0.049***	0.229***	0.232***	1

Source: Developed by the author

Notes: ***, *, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Although some explanatory variables exhibit moderate correlation, for example, between firm size and leverage, and between firm size and state ownership, the correlation coefficients are well below conventional thresholds that would indicate severe multicollinearity. To further assess potential multicollinearity concerns, variance inflation factor (VIF) tests are conducted.

The VIF results, shown in Table 3.3 indicate that all variables have VIF values substantially below the commonly accepted critical value of 10, with the maximum VIF being 1.560 and the average VIF equal to 1.260. These findings suggest that multicollinearity is not a serious concern in the empirical models. Therefore, the estimated coefficients in the subsequent regression analyses are unlikely to be distorted by collinearity among the explanatory variables, ensuring the reliability and robustness of the regression results.

Table 3.3 Variance Inflation Factor (VIF) Test Results

Variable	VIF	1/VIF
LEV	1.560	0.639
SIZE	1.550	0.645
SOE	1.270	0.789
ROA	1.190	0.838
Top1	1.120	0.894
Age	1.100	0.911
IM	1.020	0.976
Mean VIF	1.260	-

Source: Developed by the author

Notes: VIF denotes the variance inflation factor, which is used to assess the severity of multicollinearity among explanatory variables. As a commonly accepted rule of thumb, a VIF value exceeding 10 indicates serious multicollinearity. In this dissertation, all VIF values are substantially below this threshold, indicating that multicollinearity does not pose a threat to the reliability of the regression estimates.

3.2 **Baseline Regression Results**

This section presents the baseline regression results examining the impact of intelligent manufacturing on enterprise ESG performance. Following the research framework and econometric model specified in Chapter 2, a two-way fixed effects panel regression approach is employed to control for unobserved firm-specific heterogeneity and common time effects. This modeling strategy allows for a more accurate identification of the relationship between intelligent manufacturing and ESG performance by mitigating potential biases arising from time-invariant firm characteristics and macroeconomic shocks.

The baseline regressions incorporate intelligent manufacturing as the key explanatory variable and enterprise ESG performance as the dependent variable, while controlling for a comprehensive set of firm-level characteristics, including firm size, leverage, profitability, ownership structure, firm age, and industry and year fixed effects. All continuous variables are treated consistently with the data processing procedures described earlier, and standard errors are adjusted to account for potential heteroskedasticity.

The estimated results consistently indicate a positive and statistically significant relationship between intelligent manufacturing and enterprise ESG performance across different model specifications. This finding suggests that, on average, enterprises with higher levels of intelligent manufacturing tend to exhibit superior ESG performance, after controlling for other relevant firm characteristics. The baseline results provide initial empirical support for the main hypothesis of this study and establish a foundation for subsequent robustness checks, mechanism analysis, and heterogeneity examination.

3.2.1 Model Selection: Hausman Test

This chapter has provided an exhaustive account of the findings and analysis of the research methodology.To determine the appropriate panel data estimation method, this dissertation conducts a Hausman specification test to compare the fixed effects and random effects models. The null hypothesis of the Hausman test is that the difference in coefficients between the fixed effects and random effects estimators is not systematic, implying that the random effects estimator is consistent and efficient.

The test results strongly reject the null hypothesis, with a chi-square statistic of 367.54 and a p-value of 0.0000. This indicates that the coefficient differences between the fixed effects and random effects models are systematic, suggesting that the random effects estimator is inconsistent. Consequently, the fixed effects model is deemed more appropriate for the empirical analysis.

This result implies that unobserved firm-specific characteristics are correlated with the explanatory variables, and therefore must be controlled for using the fixed effects specification. Accordingly, all subsequent baseline regressions, robustness checks, mechanism analyses, and heterogeneity analyses in this dissertation are conducted based on the fixed effects panel regression framework.

Table 3.4 Hausman Test for Model Selection

Test	Chi-aquare	d.f.	Prob>Chi-square
Hausman Test	367.54	8	0.0000

Source: Developed by the author

Notes: This table reports the results of the Hausman specification test comparing fixed effects and random effects models. The null hypothesis is that the random effects estimator is consistent and efficient. A statistically significant test statistic implies that the fixed effects model should be preferred.

3.2.2 Baseline Regression Results

Table 3.5 reports the baseline regression results examining the impact of intelligent manufacturing on enterprise ESG performance. Column (1) presents the estimation results without controlling for firm and year fixed effects. The coefficient on intelligent manufacturing is positive and highly significant, indicating a strong positive association between intelligent manufacturing and ESG performance at the aggregate level.

Columns (2) and (3) report the results from two-way fixed effects models that control for unobserved firm-specific characteristics and common time effects. In column (2), intelligent manufacturing remains positively and significantly associated with ESG performance after introducing firm and year fixed effects. This suggests that the positive effect of intelligent manufacturing is not driven by time-invariant firm heterogeneity or macroeconomic shocks. The year fixed effects mainly capture common time-specific influences faced by listed firms during different periods of the sample. Therefore, if some year dummy coefficients appear negative relative to the omitted base year, this generally reflects the impact of unfavorable macroeconomic conditions, regulatory adjustments, capital-market fluctuations, pandemic-related disturbances, or changes in ESG disclosure and rating practices during those years. Such effects should be understood as average temporal influences shared across firms, rather than as evidence that intelligent manufacturing weakens ESG performance in particular years. At the same time, the coefficient of intelligent manufacturing remains positive and statistically significant after controlling for both firm and year fixed effects. This indicates that the positive relationship between intelligent manufacturing and ESG performance is not driven by common year-specific shocks, but remains relatively stable after accounting for changes in the broader external environment.

Column (3) further incorporates a comprehensive set of firm-level control variables, including firm size, leverage, profitability, ownership structure, firm age, and state ownership. The estimated coefficient of intelligent manufacturing remains positive and statistically significant, with a magnitude comparable to that in column (2). This stability across specifications indicates that the positive relationship between intelligent manufacturing and ESG performance is robust to the inclusion of control variables.

Across all specifications, intelligent manufacturing is positively and statistically significantly associated with enterprise ESG performance. Importantly, the estimated coefficient remains stable after the inclusion of firm and year fixed effects as well as additional control variables, indicating that the observed relationship is not driven by time-invariant firm characteristics or omitted variable bias. This consistency across model specifications supports the reliability of the baseline results.

Beyond statistical significance, the magnitude of the estimated coefficient suggests a meaningful economic effect. In the fully specified model reported in column (3), a one-unit increase in intelligent manufacturing is associated with an average increase of approximately 0.80 points in ESG performance, holding other factors constant. Relative to the sample distribution of ESG scores, this effect represents a substantial improvement, highlighting the important role of intelligent manufacturing as a driver of corporate sustainability outcomes. Taken together, the baseline regression results provide strong empirical support for the main hypothesis of this dissertation and motivate further analysis of the underlying mechanisms and heterogeneous effects.

Table 3.5 Baseline Regression Results of Intelligent Manufacturing on Enterprise ESG Performance

	(1)	(2)	(3)
	ESG	ESG	ESG
IM	3.0132***	0.8003**	0.8032**
	(14.41)	(2.34)	(2.36)
SIZE	0.2224***		0.2301***
	(45.78)		(16.68)
LEV	-0.9966***		-0.9527***
	(-31.01)		(-18.04)
ROA	1.3562***		-0.0519
	(18.94)		(-0.74)
Top1	0.2440***		0.0170
	(6.62)		(0.18)
Age	-0.1244***		-0.1335
	(-7.05)		(-1.06)
SOE	-0.0058		0.0043
	(-0.45)		(0.13)
Year	No	Yes	Yes
Firm	No	Yes	Yes
_cons	-0.1171	4.2254***	-0.1191
	(-1.06)	(583.41)	(-0.26)
N	30730	30347	30347
adj. R^2	0.112	0.479	0.489

Source: Developed by the author

Notes: The dependent variable is enterprise ESG performance. IM denotes intelligent manufacturing. Firm and year fixed effects are included as indicated. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

3.3 Robustness Checks

3.3.1 Replacement of Independent Variables

To ensure that the baseline results are not driven by the specific measurement of intelligent manufacturing, this dissertation conducts a robustness check by adopting an alternative proxy for intelligent manufacturing based on textual analysis of corporate disclosures. Specifically, following the emerging literature on digital transformation and intelligent manufacturing measurement, an alternative indicator (IM2) is constructed using the frequency of intelligent manufacturing-related keywords disclosed in firms' annual reports.

Compared with index-based or efficiency-based measures, the text-based approach captures enterprises' strategic orientation and disclosure intensity toward intelligent manufacturing from an output and communication perspective. Although such measures may be subject to contextual interpretation and disclosure incentives, they provide a complementary lens to assess enterprises' engagement in intelligent manufacturing practices. Employing this alternative proxy allows us to examine whether the positive relationship between intelligent manufacturing and ESG performance persists under a substantially different measurement framework.

Table 3.6 reports the regression results using IM2 as the core explanatory variable. The coefficient on IM2 remains positive and statistically significant at the 1% level (coefficient = 0.0015, t = 3.19), indicating that enterprises with higher levels of intelligent manufacturing related disclosure exhibit significantly better ESG performance. This finding is fully consistent with the baseline results obtained using the primary intelligent manufacturing index, thereby reinforcing Hypothesis H1.

Overall, the robustness check using an alternative, disclosure-based measure of intelligent manufacturing confirms that the positive impact of intelligent manufacturing on enterprise ESG performance is not sensitive to variable measurement choices. The consistency across different proxies enhances the credibility of the empirical findings and supports the argument that intelligent manufacturing exerts a substantive and robust influence on firms' ESG outcomes, rather than reflecting a methodological artifact.

Table 3.6 Robustness Check: Alternative Measure of Intelligent Manufacturing

	(Change Independent Variable)
	ESG
IM2	0.0015***
	(3.19)
SIZE	0.2280***
	(16.49)
LEV	-0.9535***
	(-18.06)
ROA	-0.0560
	(-0.80)
Top1	0.0199
	(0.21)
Age	-0.1400
	(-1.11)
SOE	0.0060
	(0.19)
Year	Yes
Firm	Yes
_cons	-0.0486
	(-0.10)
N	30347
adj. R^2	0.489

Source: Developed by the author

Notes: The independent variable is IM2 measured using the frequency of intelligent manufacturing related keywords from the CSMAR database. The dependent variable is ESG performance. Firm and year fixed effects are included. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

3.3.2 Replacement of Dependent Variables

To examine whether the baseline results are sensitive to the measurement of ESG performance, this dissertation conducts a robustness check by replacing the original ESG rating based on the Huazheng ESG database with an alternative ESG rating obtained from the WIND database. The regression specification remains consistent with the baseline model, including firm and year fixed effects as well as the full set of control variables.

The results are reported in Table 3.7. The estimated coefficient of intelligent manufacturing remains positive and statistically significant, indicating that enterprises with higher levels of intelligent manufacturing tend to exhibit better ESG performance even when ESG is measured using an alternative rating system. Although the magnitude of the coefficient is smaller than that in the baseline regression, the direction and significance of the effect are consistent with the main findings.

Overall, this robustness check suggests that the positive relationship between intelligent manufacturing and enterprise ESG performance is not driven by a specific ESG rating methodology. The baseline conclusions therefore remain valid under alternative measures of ESG performance.

Table 3.7 Robustness Check: Alternative Measure of ESG Performance

	(Change Dependent Variable)
	ESG2
IM	0.4133*
	(1.94)
SIZE	-0.1398***
	(-5.49)
LEV	0.5364***
	(5.51)
ROA	-0.2878**
	(-2.22)
Top1	-0.1732
	(-0.99)
Age	0.1966
	(0.85)
SOE	0.2768***
	(4.65)
Year	Yes
Firm	Yes
_cons	3.9336***

	(4.60)
N	30347
adj. R^2	0.747

Source: Developed by the author

Notes: The dependent variable is ESG performance measured using the WIND ESG rating. IM denotes intelligent manufacturing. Firm and year fixed effects are included. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

3.3.3 Excluding COVID-19 Period

To further examine whether the baseline results are influenced by the COVID-19 pandemic, this dissertation conducts an additional robustness check by excluding observations from the pandemic period. The regression specification remains consistent with the baseline model, including firm and year fixed effects as well as the full set of control variables.

The results are reported in Table 3.8. The estimated coefficient of intelligent manufacturing remains positive and statistically significant after excluding pandemic years, indicating that the positive relationship between intelligent manufacturing and enterprise ESG performance is not driven by extraordinary macroeconomic shocks. Notably, the magnitude of the coefficient is comparable to, and slightly larger than, that in the baseline regression, suggesting that intelligent manufacturing continues to play a substantive role in enhancing ESG performance under normal economic conditions.

Overall, these findings confirm that the main conclusions of this dissertation are robust to the exclusion of the COVID-19 period.

Table 3.8 Robustness Check: Excluding COVID-19 Period

	(Excluding COVID-19 Period)
	ESG
IM	1.1217**
	(2.51)
SIZE	0.2404***
	(13.15)
LEV	-0.8950***
	(-13.00)
ROA	-0.0290
	(-0.36)
Top1	0.2272*
	(1.84)
Age	-0.4596***
	(-2.59)
SOE	0.0121
	(0.28)
Year	Yes

Firm	Yes
_cons	0.4922
	(0.77)
N	20670
adj. R^2	0.572

Source: Developed by the author

Notes: The dependent variable is enterprise ESG performance. Observations from the COVID-19 period are excluded. IM denotes intelligent manufacturing. Firm and year fixed effects are included. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The comparison between the baseline results and the results after excluding the COVID-19 period provides a clearer interpretation of the pandemic-related influence. COVID-19 may have affected enterprises' production continuity, supply-chain stability, financing conditions, ESG disclosure pressure, and sustainability-related investment. Therefore, if the positive effect of intelligent manufacturing on ESG performance were mainly driven by the special circumstances of the pandemic period, the coefficient of intelligent manufacturing would be expected to change substantially after removing these observations. However, the results in Table 3.8 show that the positive relationship between intelligent manufacturing and enterprise ESG performance remains stable after excluding the COVID-19 period. This indicates that the main conclusion is not dependent on pandemic-period shocks.

It should be noted that this test is not intended to estimate the independent causal effect of COVID-19. Instead, it serves as a robustness check to examine whether the baseline conclusion remains valid after removing observations that may be affected by this extraordinary external shock. In this sense, the evidence suggests that the ESG enhancing effect of intelligent manufacturing is not limited to the pandemic context, but reflects a more general and stable relationship between intelligent transformation and enterprise sustainability performance.

3.3.4 Clustered Standard Errors

To address potential concerns regarding heteroskedasticity and serial correlation within enterprises, this dissertation conducts an additional robustness check by estimating the baseline model using clustered standard errors at the firm level. This approach allows for arbitrary correlation of the error terms within each firm over time and provides more conservative inference.

The results are reported in Table 3.9. The estimated coefficient of intelligent manufacturing remains positive and statistically significant when clustered standard errors are employed. Importantly, the point estimate of the coefficient is identical to that in the baseline regression, indicating that the substantive effect of intelligent manufacturing on ESG performance is unchanged. The persistence of statistical significance under a more stringent inference framework suggests that the baseline results are not driven by underestimated standard errors.

Overall, these findings further reinforce the robustness of the positive relationship between intelligent manufacturing and enterprise ESG performance.

Table 3.9 Robustness Check Using Clustered Standard Errors

	(Using Clustered Standard Errors)
	ESG
IM	0.8032*
	(1.93)
SIZE	0.2301***
	(10.83)
LEV	-0.9527***
	(-12.44)
ROA	-0.0519
	(-0.57)
Top1	0.0170
	(0.12)
Age	-0.1335
	(-0.71)
SOE	0.0043
	(0.08)
Year	Yes
Firm	Yes
_cons	-0.1191
	(-0.17)
N	30347
adj. R^2	0.489

Source: Developed by the author

Notes: The dependent variable is enterprise ESG performance. IM denotes intelligent manufacturing. Standard errors are clustered at the firm level. Firm and year fixed effects are included. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

3.3.5 Propensity Score Matching Test

To further mitigate potential endogeneity concerns, particularly those arising from non-random selection into intelligent manufacturing adoption, this dissertation employs a propensity score matching (PSM) approach combined with a difference-in-differences (DID) specification. The key concern is that enterprises with stronger resources, better governance, or more favorable operating conditions may be more likely to adopt intelligent manufacturing, and these preexisting characteristics may simultaneously influence ESG performance. If not properly addressed, such selection may bias the estimated effect of intelligent manufacturing on ESG performance.

Defining treated and control groups

Consistent with the baseline analysis, enterprises that adopt intelligent manufacturing constitute the treatment group, while firms that do not adopt intelligent manufacturing serve as the control group. The treatment indicator is constructed based on the intelligent manufacturing variable (IM) defined in Chapter 2.

Estimation of propensity scores

Propensity scores are estimated using a logit model, where the dependent variable indicates whether an enterprise adopts intelligent manufacturing. The explanatory variables include a set of firm-level characteristics measured prior to treatment, which are theoretically and empirically related to both intelligent manufacturing adoption and ESG performance. Specifically, the covariates used for matching include firm size (SIZE), leverage (LEV), profitability (ROA), ownership concentration (Top1), firm age (Age), and state ownership (SOE). These variables are consistent with the control variables used in the baseline fixed-effects regressions, ensuring coherence across empirical strategies.

Matching algorithm and implementation

Based on the estimated propensity scores, this dissertation applies nearest-neighbor matching with a ratio of 1:20, meaning that each treated enterprise is matched with up to twenty control enterprises with the closest propensity scores. This matching ratio is chosen to reflect the relative size of the treatment and control groups in the sample and to retain sufficient information from the control group while maintaining comparability. Using multiple matched controls for each treated enterprise improves estimation efficiency and reduces variance without substantially increasing bias, particularly when the pool of control enterprises is large relative to the treated group.

To further enhance match quality, a caliper restriction is imposed to ensure that matched control enterprises fall within a sufficiently narrow propensity score distance from treated enterprises. Matching is conducted without replacement, such that each control enterprise can be matched to at most one treated enterprise. This approach avoids overweighting specific control observations and preserves the independence of matched pairs. Observations outside the region of common support are excluded to prevent extrapolation beyond comparable enterprises.

Rational for the PSM-DID approach

The PSM procedure mitigates selection bias stemming from observable enterprise characteristics by constructing a matched sample with comparable treatment and control groups. The subsequent DID estimation further controls for time-invariant unobserved heterogeneity and common macroeconomic shocks. By combining PSM with DID, the analysis strengthens causal inference by addressing both observable and unobservable sources of endogeneity.

Covariate Balance Test

To assess the quality of the propensity score matching procedure, a covariate balance test is conducted by comparing the distributions of key firm characteristics between the treated and control groups before and after matching.

The covariate balance diagnostics are reported in Table 3.10. In addition to the difference in means between the treated and control groups, the table reports the t-statistic and p-value from the equality-of-means test, as well as the standardized bias (%bias), which is interpreted here as an effect-size measure of covariate imbalance. In propensity score matching diagnostics, the standardized bias is particularly informative because it is scale-free and less sensitive to sample size than hypothesis-testing results alone. Following common practice, lower absolute values of standardized bias indicate better balance, and values below 10 percent are generally considered acceptable.

Before matching, some covariates exhibit nontrivial imbalances between the treated and control groups. For example, the standardized bias for firm size reaches 23.10 percent in the unmatched sample, indicating a substantial pre-matching difference in observable characteristics. After matching, the balance improves markedly. The absolute standardized biases for all covariates fall to very low levels, ranging from 0.17 to 0.46, and the percentage reduction in absolute bias ranges from 81.6 percent to 98.8 percent. At the same time, the post-matching t-statistics are all small in absolute value, and the corresponding p-values are well above conventional significance levels, suggesting that there are no statistically significant remaining differences in covariate means between the treated and matched control groups.

Taken together, the effect-size diagnostics and the post-matching t-tests indicate that the matching procedure substantially improves comparability between the two groups. Therefore, the matched sample provides a more credible basis for the subsequent DID estimation reported in Table 3.11.

Table 3.10 Covariate Balance Test Before and After Propensity Score Matching

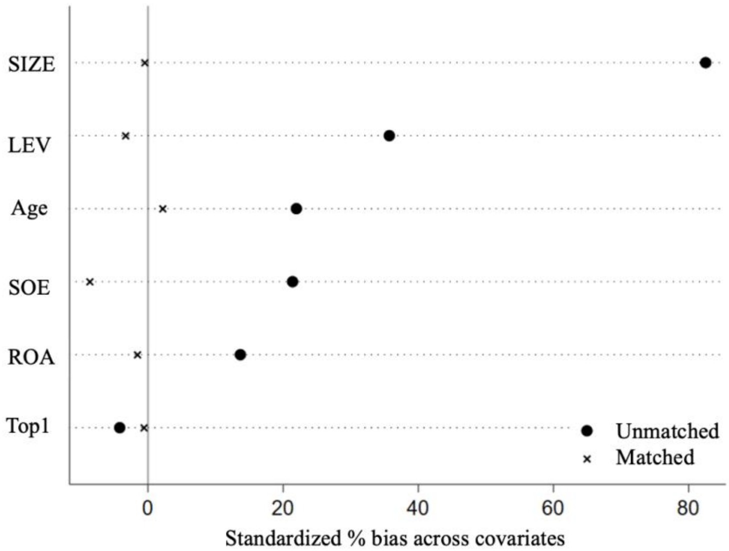
	Unmatched	Mean			%Reduction	T-Test	
Variable	Matched	Treated	Control	Std. Bias (%)	|Std. bias |	t	p > | t |

				/Effect Size			
SIZE	U	23.3	22.25	23.10		1.03	0.300
	M	23.3	23.28	0.2	98.8	0.85	0.396
LEV	U	0.468	0.404	9.21		0.73	0.466
	M	0.468	0.471	-0.35	95.1	0.73	0.465
ROA	U	0.0445	0.0341	3.84		0.50	0.617
	M	0.0445	0.0456	-0.37	89.7	0.71	0.478
Top1	U	0.331	0.332	-0.06		0.95	0.343
	M	0.331	0.328	0.46	91.5	0.65	0.515
Age	U	3.045	3.010	3.27		0.74	0.459
	M	3.045	3.051	-0.46	81.6	0.65	0.516
SOE	U	0.411	0.291	7.61			
	M	0.411	0.415	-0.17	96.6	0.87	0.386

Source: Developed by the author

Notes: U and M denote unmatched and matched samples, respectively. Std. Bias (%) / Effect Size reports the standardized mean difference between treated and control groups and is interpreted as an effect-size measure of covariate imbalance. Lower absolute values indicate better balance, and values below 10 percent are generally viewed as evidence of acceptable covariate balance. % Reduction in |Std. Bias| measures the percentage decline in absolute standardized bias after matching. The reported t-statistics and p-values are from equality-of-means tests between the treated and control groups; smaller absolute t-values and statistically insignificant p-values after matching provide additional evidence of improved balance, although standardized bias remains the primary balance diagnostic.

Figure 3.1 PSM propensity score matching plot.



Source: Developed by the author

PSM-DID Estimation Results

Based on the matched sample, a DID regression is estimated to quantify the causal impact of intelligent manufacturing on enterprise ESG performance. The DID specification includes firm and year fixed effects, as well as the same set of control variables used in the baseline regressions. The key coefficient of interest is the interaction term between the treatment indicator and the post-adoption period (did).

The estimation results are reported in Table 3.11. The coefficient on the DID interaction term is positive and statistically significant, indicating that enterprises adopting intelligent manufacturing experience a significant improvement in ESG performance relative to comparable non-adopting enterprises. This result suggests that the positive association between intelligent manufacturing and ESG performance identified in the baseline regressions reflects a causal effect rather than being driven by selection bias.

Because the post-matching balance diagnostics show both very small standardized biases and statistically insignificant mean differences, the matched sample is considered sufficiently balanced for subsequent DID estimation.

Table 3.11 PSM-DID Estimation Results of Intelligent Manufacturing on Enterprise ESG Performance

	(1) ESG
DID	0.1256*
	(1.71)
SIZE	0.3587***
	(12.67)
LEV	-1.0955***
	(-9.92)
ROA	-0.2271
	(-1.26)
Top1	-0.1142
	(-0.66)
Age	0.7683***
	(3.36)
SOE	0.0231
	(0.38)
_cons	-5.7199***
	(-6.38)
N	10823
adj. R^2	0.500

Source: Developed by the author

Notes: The dependent variable is enterprise ESG performance. The DID variable captures the interaction between treatment group and post-adoption period. The sample is obtained using 1:20 nearest-neighbor propensity score matching with caliper and without replacement. Firm and year fixed effects are included. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

3.4 **Endogeneity Test: System GMM Estimation**

To further address potential endogeneity concerns arising from dynamic persistence, this dissertation employs the System Generalized Method of Moments (System GMM) estimator.

The reverse-causality concern is relevant because enterprises with better ESG performance may have stronger financial resources, more standardized governance systems, and higher external recognition, which may make them more capable of adopting intelligent manufacturing. At the same time, ESG performance is likely to be persistent over time, since environmental management, social responsibility practices, governance quality, and disclosure systems are accumulated gradually. Therefore, a dynamic panel specification including the lagged dependent variable is introduced:

$$\mathrm{ESG}_{i,t} = \alpha_0 + \alpha_3 ESG_{i,t-1} + \alpha_1 IM_{i,t} + \sum_{\mathrm{j}} \alpha_2 Control_{j,i,t} + \mu_i + \lambda_i + \epsilon_{i,t} \quad (3.1)$$

After the lagged dependent variable is included, traditional fixed-effects estimation may be biased. System GMM is selected because it uses internal instruments based on lagged variables and combines the level equation with the differenced equation, which helps mitigate the endogeneity of the lagged dependent variable and the potential endogeneity of intelligent manufacturing. This approach is consistent with the data structure of this dissertation, which contains a relatively large number of firms observed over a limited period from 2015 to 2023.

Difference GMM is not selected as the main estimator because ESG performance and intelligent manufacturing may show persistence over time. In this situation, lagged levels may provide weak instruments for first-differenced variables, and first differencing may also remove useful cross-sectional information. System GMM is therefore more suitable for improving estimation efficiency in this dynamic panel setting. Panel VAR is also not adopted as the main method because the purpose of this dissertation is not to estimate a full dynamic feedback system among multiple endogenous variables, but to test a theory-driven relationship in which intelligent manufacturing affects ESG performance through specific mediating mechanisms. Therefore, System GMM is more consistent with the research hypothesis, data structure, and mechanism-oriented empirical design of this dissertation.

The estimation results are reported in Table 3.12. The coefficient on the lagged ESG variable is positive and highly significant, indicating substantial persistence in enterprises' ESG performance. More importantly, the coefficient on intelligent manufacturing remains positive and statistically significant after controlling for dynamic effects and potential endogeneity, suggesting that the baseline findings are robust to endogeneity concerns.

Diagnostic tests support the validity of the System GMM specification. The AR(1) test indicates first-order serial correlation, as expected, while the AR(2) test fails to reject the null hypothesis of no second-order serial correlation. In addition, the Hansen test does not reject the null hypothesis of instrument validity, indicating that the chosen instrument set is appropriate.

Overall, the System GMM results provide further evidence that intelligent manufacturing exerts a positive and robust impact on enterprise ESG performance.

These results should be interpreted as complementary evidence that the baseline conclusion remains robust after considering dynamic persistence and potential reverse causality. The System GMM estimation does not serve as the only source of causal evidence in this dissertation. Rather, together with the following PSM-DID analysis and dynamic lagged-effect test, it strengthens the empirical basis for the conclusion that the positive relationship between intelligent manufacturing and ESG performance is not merely driven by the possibility that firms with better ESG performance are more likely to adopt intelligent manufacturing.

Table 3.12 Endogeneity Test: System GMM Estimation Results

	(1)
	ESG
L.ESG	0.4725***
	(3.89)
IM	3.3859*
	(1.92)
SIZE	0.1328
	(0.41)
LEV	0.2915
	(0.06)
ROA	-1.0384
	(-0.40)
Top1	-6.9996*
	(-1.71)
Age	0.2489
	(0.17)
SOE	1.5461
	(0.86)
Year	Yes
Firm	Yes
AR1	0.000
AR2	0.119
Hansen test	0.117
_cons	-0.5218
	(-0.08)
N	23129
adj. R^2	0.500

Source: Developed by the author

Notes: The dependent variable is enterprise ESG performance. L.ESG denotes the one-period lag of ESG. IM represents intelligent manufacturing. The model is estimated using the System GMM method. Firm and year fixed effects are included. AR(1) and AR(2) report tests for first- and second-order serial correlation in first differenced errors. The Hansen test examines the validity of the instruments. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

3.5 Dynamic Lagged-Effect Test

To further address the possibility that the ESG implications of intelligent manufacturing unfold gradually rather than contemporaneously, this dissertation conducts an additional dynamic lagged-effect test. This step is theoretically necessary because intelligent manufacturing is not a one-off technological input whose consequences can be fully realized within the same period. Instead, it typically involves a cumulative process of equipment upgrading, digital-system integration, organizational adjustment, managerial learning, and capability reconfiguration. As a result, its effect on enterprise ESG performance may emerge with a temporal lag. To examine this issue, the dependent variable is successively replaced by ESG performance in period t+1, period t+2, and period t+3, while the core explanatory variable and control variables remain unchanged.

Table 3.13 Dynamic Lagged Effects of Intelligent Manufacturing on Enterprise ESG Performance

	(1) L.ESG	(2) L2.ESG	(3) L3.ESG
IM	1.1306***	2.1015***	1.8109***
	(2.89)	(4.80)	(3.66)
SIZE	0.2293***	0.2362***	0.2179***
	(13.61)	(11.69)	(8.92)
LEV	-0.6436***	-0.3857***	-0.2354***
	(-10.23)	(-5.27)	(-2.79)
ROA	-0.3914***	-0.5830***	-0.4908***
	(-5.12)	(-7.10)	(-5.66)
TOP1	0.0704	0.3242**	0.4463***
	(0.63)	(2.52)	(2.98)
Age	-0.2657	-0.7450***	-1.2922***
	(-1.58)	(-3.33)	(-4.28)
SOE	-0.0710**	-0.1199***	-0.1718***
	(-1.98)	(-3.01)	(-3.80)
Year	No	Yes	Yes
Firm	No	Yes	Yes
_cons	0.1683	1.2042	3.1699***
	(0.29)	(1.57)	(3.09)
N	25265	20669	16639
adj. R^2	-0.203	-0.230	-0.253

Source: Developed by the author

Notes: Columns (1) - (3) report regressions in which the dependent variable is enterprise ESG performance in period t+1, period t+2, and period t+3, respectively. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3.13 shows that the coefficient on IM remains positive and statistically significant in all three specifications. Specifically, the coefficient on IM is 1.1306 when the dependent variable is ESG performance in period t+1, 2.1015 when the dependent variable is ESG performance in period t+2, and 1.8109 when the dependent variable is ESG performance in period t+3; all three estimates are significant at the 1% level. These results indicate that the effect of intelligent manufacturing on enterprise ESG performance is not confined to the contemporaneous period, but persists over time and exhibits a clear dynamic pattern.

Notably, the estimated coefficient is largest in the two-period-ahead specification, suggesting that the ESG implications of intelligent manufacturing become more pronounced after an initial adjustment period. This pattern is consistent with the organizational logic of intelligent transformation. While certain improvements, such as enhanced data visibility and process monitoring, may begin to appear relatively early, broader ESG gains often require more time to materialize because they depend on deeper organizational integration, cross-functional coordination, and the gradual translation of technological upgrading into governance, environmental, and social outcomes.

At the same time, the coefficient remains significantly positive in the three-period-ahead specification, although its magnitude is somewhat lower than that in the two-period-ahead model. This suggests that the ESG enhancing effect of intelligent manufacturing remains durable over time, while the most pronounced gains may emerge after the initial implementation stage and then gradually stabilize. To conclude, the results show that the impact of intelligent manufacturing on enterprise ESG performance is characterized by delayed realization and sustained influence, rather than by an immediate one-period response alone.

This finding adds an important dynamic dimension to the baseline results. It suggests that intelligent manufacturing should be understood as a medium to long-cycle organizational transformation whose sustainability benefits are released progressively over time. In substantive terms, the estimates indicate that the positive ESG effect begins to emerge within one period, becomes more pronounced in the second period, and remains significantly positive through the third period.

3.6 Mediating Effect Analysis

3.6.1 Information Transparency

To further explore the underlying mechanism through which intelligent manufacturing affects enterprise ESG performance, this dissertation examines the mediating role of information transparency. Information transparency reflects the extent to which enterprises disclose accurate, timely, and comprehensive information to external stakeholders, which is expected to influence ESG evaluation outcomes.

The mediation analysis is conducted following a stepwise regression approach. The results are reported in Table 3.14. Column (1) shows that intelligent manufacturing has a positive and statistically significant effect on ESG performance, confirming the existence of a total effect. Column (2) indicates that intelligent manufacturing significantly improves information transparency, suggesting that enterprises adopting intelligent manufacturing tend to exhibit higher levels of disclosure quality and information openness.

Column (3) incorporates both intelligent manufacturing and information transparency into the ESG regression. The coefficient on information transparency is statistically significant, while the coefficient on intelligent manufacturing remains positive and significant. This pattern indicates that information transparency partially mediates the relationship between intelligent manufacturing and ESG performance.

Table 3.14 Mediating Analysis: Information Transparency

	(1)	(2)	(3)
	ESG	TRANS	ESG
IM	0.9933***	0.1905***	1.0103***
	(2.80)	(2.85)	(2.85)
SIZE	0.2426***	0.0324***	0.2455***
	(16.72)	(11.85)	(16.87)
LEV	-0.8741***	0.1240***	-0.8631***
	(-15.80)	(11.90)	(-15.55)
ROA	-0.0727	-0.0068	-0.0733
	(-1.01)	(-0.50)	(-1.02)
Top1	-0.0927	-0.1594***	-0.1069
	(-0.95)	(-8.69)	(-1.10)
Age	-0.0082	0.4570***	0.0325
	(-0.06)	(17.35)	(0.23)
SOE	0.0084	0.0027	0.0086
	(0.25)	(0.44)	(0.26)
TRANS			0.0889**
			(2.57)
Year	Yes	Yes	Yes
Firm	Yes	Yes	Yes
_cons	-0.8018	-1.9637***	-0.9765*
	(-1.56)	(-20.28)	(-1.88)
N	30347	30347	30347
adj. R^2	0.498	0.360	0.498

Source: Developed by the author

Notes: The dependent variables are ESG performance and information transparency (TRANS). IM denotes intelligent manufacturing. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

To further validate the mediating effect, this dissertation supplements the Sobel-Goodman tests with bootstrap estimation. As reported in Table 3.15, the Sobel-Goodman results confirm that the indirect effect of intelligent manufacturing on enterprise ESG performance through information transparency is statistically significant. The bootstrap results in Table 3.16 further reinforce this conclusion. The estimated indirect effect is positive, and the corresponding 95% bootstrap confidence interval excludes zero, which indicates that the mediating role of information transparency remains statistically significant under repeated resampling. Meanwhile, the direct effect of intelligent manufacturing remains positive and significant after the inclusion of information transparency, suggesting that the relationship is characterized by partial rather than full mediation. Taken together, these results provide more robust evidence that intelligent manufacturing contributes to enterprise ESG performance not only directly, but also indirectly by improving information disclosure quality and reducing information asymmetry.

Table 3.15 Sobel-Goodman Tests for the Mediating Effect of Information Transparency

Test	Coefficient	Std.Error	Z-statistic	p-value
Sobel test	0.04748904	0.01160498	4.092	0.00004274
Goodman-1 (Aroian)	0.04748904	0.01168108	4.065	0.00004794
Goodman-2	0.04748904	0.01152837	4.119	0.000038
Effect decomposition				
Indirect effect	0.047489	0.011605	4.09213	0.000043
Direct effect	2.9267	0.224033	13.0637	0.000
Total effect	2.97419	0.224132	13.2698	0.000
Proportion mediated	0.01596704			

Source: Developed by the author

Notes: This table reports Sobel and Goodman tests for the mediating effect of information transparency. Indirect, direct, and total effects are calculated based on the mediation framework. Z-statistics and corresponding p-values are reported.

Table 3.16 Bootstrap Test for the Mediating Effect of Information Transparency

Effect	Coefficient	Bootstrap Std.Err.	Z-statistic	p-value	95% Bootstrap Confidence Interval
Indirect effect	0.0169	0.005682	2.97	0.001	[0.0025126,0.0091063]
Direct effect	1.0307	0.364584	2.62	0.001	[0.3985367,1.9164232]

Source: Developed by the author

Notes: This table reports bootstrap estimates for the indirect and direct effects of intelligent manufacturing on enterprise ESG performance through information transparency. The indirect effect is calculated as the product of the coefficient of intelligent manufacturing on information transparency and the coefficient of information transparency on ESG performance. The direct effect refers to the coefficient of intelligent manufacturing on ESG performance after controlling for the mediating variable. A mediating effect is considered statistically significant when the bootstrap confidence interval does not include zero.

3.6.2 Green Technological Innovation

To further investigate the mechanisms through which intelligent manufacturing affects enterprise ESG performance, this dissertation examines the mediating role of green technological innovation. Green technological innovation reflects enterprises' efforts in developing and applying environmentally friendly technologies and processes, which is closely related to sustainable development outcomes.

The mediation analysis is conducted using a stepwise regression approach, and the results are reported in Table 3.17 Column (1) shows that intelligent manufacturing has a positive and statistically significant effect on ESG performance, indicating a strong total effect. Column (2) demonstrates that intelligent manufacturing significantly promotes green technological innovation, suggesting that enterprises adopting intelligent manufacturing are more likely to engage in green innovation activities.

Column (3) incorporates both intelligent manufacturing and green technological innovation into the ESG regression. The coefficient on green technological innovation is positive and statistically significant, while the coefficient on intelligent manufacturing remains positive and significant. This pattern indicates that green technological innovation partially mediates the relationship between intelligent manufacturing and ESG performance.

Table 3.17 Mediation Analysis: Green Technological Innovation

	(1) ESG	(2) GTI	(3) ESG
IM	0.8032**	0.1970**	0.7963**
	(2.36)	(1.97)	(2.34)
SIZE	0.2301***	0.0472***	0.2285***
	(16.68)	(11.65)	(16.52)
LEV	-0.9527***	-0.0227	-0.9519***
	(-18.04)	(-1.46)	(-18.02)
ROA	-0.0519	-0.0191	-0.0513
	(-0.74)	(-0.93)	(-0.73)
Top1	0.0170	0.1672***	0.0112
	(0.18)	(6.01)	(0.12)
Age	-0.1335	-0.5381***	-0.1147
	(-1.06)	(-14.58)	(-0.91)
SOE	0.0043	-0.0128	0.0047
	(0.13)	(-1.36)	(0.15)
GTI			0.0350*
			(1.65)
Year	Yes	Yes	Yes
Firm	Yes	Yes	Yes
_cons	-0.1191	0.6218***	-0.1409
	(-0.26)	(4.56)	(-0.30)
N	30347	30347	30347

adj. R^2	0.489	0.832	0.489

Source: Developed by the author

Notes: The dependent variables are ESG performance and green technological innovation (GTI). IM denotes intelligent manufacturing. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

To further validate the mediating effect, this dissertation supplements the Sobel-Goodman tests with bootstrap estimation. As reported in Table 3.18, the Sobel-Goodman results confirm that the indirect effect of intelligent manufacturing on enterprise ESG performance through green technological innovation is statistically significant. The bootstrap results shown in Table 3.19 further support this finding. The estimated indirect effect is positive, and its 95% bootstrap confidence interval excludes zero, indicating that the mediating role of green technological innovation remains statistically significant under repeated resampling. Therefore, the evidence consistently suggests that intelligent manufacturing contributes to enterprise ESG performance not only through its direct effect identified in the mediation regressions, but also indirectly by promoting green technological innovation.

Table 3.18 Sobel-Goodman Tests for the Mediating Effect of Green Technological Innovation

Test	Coefficient	Std.Error	Z-statistic	p-value
Sobel test	0.04708047	0.01109334	4.244	0.00002195
Goodman-1 (Aroian)	0.04708047	0.01116149	4.218	0.00002464
Goodman-2	0.04708047	0.01102476	4.27	0.00001951
Effect decomposition				
Indirect effect	0.04708	0.011093	4.24403	0.000022
Direct effect	2.94977	0.215968	13.6584	0.000
Total effect	2.99685	0.21606	13.8705	0.000
Proportion mediated	0.01570996			

Source: Developed by the author

Notes: This table reports Sobel and Goodman tests for the mediating effect of green technological innovation. Indirect, direct, and total effects are calculated based on the mediation framework. Z-statistics and corresponding p-values are reported.

Table 3.19 Bootstrap Test for the Mediating Effect of Green Technological Innovation

Effect	Coefficient	Bootstrap Std.Err.	Z-statistic	p-value	95% Bootstrap Confidence Interval
Indirect effect	0.004695	0.000950	4.94	< 0.001	[0.003087, 0.006713]
Direct effect	0.012409	0.011032	1.12	0.261	[-0.008535, 0.034806]

Source: Developed by the author

Notes: This table reports bootstrap estimates for the indirect and direct effects of intelligent manufacturing on enterprise ESG performance through green technological innovation. The bias-corrected (BC) 95% bootstrap confidence interval is reported. A mediating effect is considered statistically significant when the bootstrap confidence interval does not include zero.

3.6.3 Financing Constraints

Financing constraints are examined as the third mediating mechanism because they reflect whether enterprises have sufficient financial resources to convert intelligent manufacturing into ESG related investment. Intelligent manufacturing may improve ESG performance not only through technological and organizational capability, but also through its influence on enterprises' financing conditions. If intelligent manufacturing improves operational efficiency, process transparency, and credit recognition, it may alleviate financing constraints and strengthen enterprises' ability to invest in environmental protection, social responsibility, and governance improvement. Conversely, if financing constraints remain severe, the capital demand associated with intelligent transformation may weaken enterprises' capacity to sustain ESG related activities. Therefore, the KZ index is used to test the financing-resource channel linking intelligent manufacturing and enterprise ESG performance.

The mediation analysis is conducted following a stepwise regression approach, and the results are reported in Table. 3.20 Column (1) confirms that intelligent manufacturing has a positive and statistically significant effect on ESG performance. Column (2) shows that intelligent manufacturing significantly affects enterprises' financing constraints, indicating that the adoption of intelligent manufacturing is associated with changes in enterprises' financing conditions.

Column (3) incorporates both intelligent manufacturing and financing constraints into the ESG regression. The coefficient on financing constraints is negative, suggesting that tighter financing constraints inhibit ESG performance. Meanwhile, the coefficient on intelligent manufacturing remains positive and becomes larger in magnitude after controlling for financing constraints.

Table 3.20 Mediation Analysis: Financing Constraints

	(1) ESG	(2) KZ	(3) ESG
IM	0.8332^{**}	-5.5291^{***}	0.8062^{**}
	(2.36)	(-8.74)	(2.44)
SIZE	0.2301^{***}	-0.5048^{***}	0.2277^{***}
	(16.68)	(-19.69)	(16.38)
LEV	-0.9527^{***}	6.6316^{***}	-0.9200^{***}
	(-18.04)	(67.58)	(-16.05)
ROA	-0.0519	-5.1765^{***}	-0.0774
	(-0.74)	(-39.64)	(-1.07)
Top1	0.0170	-0.2716	0.0157
	(0.18)	(-1.54)	(0.17)
Age	-0.1335	3.4423^{***}	-0.1166
	(-1.06)	(14.74)	(-0.92)

SOE	0.0043	-0.0336	0.0041
	(0.13)	(-0.56)	(0.13)
KZ			-0.0049*
			(-1.65)
Year	Yes	Yes	Yes
Firm	Yes	Yes	Yes
_cons	-0.1191	-0.5346	-0.1218
	(-0.26)	(-0.62)	(-0.26)
N	30347	30347	30347
adj. R^2	0.489	0.717	0.489

Source: Developed by the author

Notes: The dependent variables are ESG performance and financing constraints (KZ index). IM denotes intelligent manufacturing. A higher value of the KZ index indicates stronger financing constraints. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

To further assess the mediating effect, this dissertation supplements the Sobel-Goodman tests with bootstrap estimation. As shown in Table 3.21, intelligent manufacturing significantly reduces financing constraints, and tighter financing constraints are negatively associated with enterprise ESG performance. The bootstrap results reported in Table 3.22 further reinforce this conclusion. The estimated indirect effect is positive, and the corresponding 95% bootstrap confidence interval excludes zero, indicating that the mediation channel through financing constraints is statistically significant under repeated resampling. Meanwhile, the direct effect of intelligent manufacturing on ESG performance remains positive and statistically significant, suggesting that financing constraints play a partial mediating role in the relationship between intelligent manufacturing and enterprise ESG performance. Overall, these findings indicate that intelligent manufacturing enhances ESG performance not only directly, but also indirectly by alleviating financing constraints.

Table 3.21 Sobel-Goodman Tests for the Mediating Effect of Financing Constraints

Test	Coefficient	Std.Error	Z-statistic	p-value
Sobel test	-0.13992914	-0.01847976	-7.572	0.000
Goodman-1 (Aroian)	-0.13992914	0.01851785	-7.556	0.000
Goodman-2	-0.13992914	0.0184416	-7.588	0.000
Effect decomposition				
Indirect effect	-0.139929	0.01848	-7.57202	0.000
Direct effect	3.04523	0.208375	14.6154	0.000
Total effect	2.90531	0.208544	13.9314	0.000
Proportion mediated	-0.04816332			

Source: Developed by the author

Notes: This table reports Sobel and Goodman tests for the mediating effect of financing constraints. Indirect, direct, and total effects are calculated based on the mediation framework. Z-statistics and corresponding p-values are reported.

Table 3.22 Bootstrap Test for the Mediating Effect of Financing Constraints

Effect	Coefficient	Bootstrap Std.Err.	Z-statistic	p-value	95% Bootstrap Confidence Interval
Indirect effect	0.002976	0.000327	9.09	<0.001	[0.002374, 0.003645]
Direct effect	0.834635	0.200618	2.87	0.001	[0.305197,1.291524]

Source: Developed by the author

Notes: This table reports bootstrap estimates for the indirect and direct effects of intelligent manufacturing on enterprise ESG performance through financing constraints. The bias-corrected (BC) 95% bootstrap confidence interval is reported. A mediating effect is considered statistically significant when the bootstrap confidence interval does not include zero.

3.6.4 Synergistic Governance

The mediating role of synergistic governance is examined through DEM index, which serves as a proxy for digitally enabled governance coordination rather than general corporate governance quality, to further examine whether organizational coordination constitutes an internal channel through which intelligent manufacturing enhances enterprise ESG performance. Synergistic governance captures the enterprise's capacity to coordinate internal functions and relevant external stakeholders through more integrated governance arrangements, digital interfaces, and data-enabled management processes. Because ESG performance depends not only on isolated managerial decisions but also on the quality of coordination across production, compliance, environmental management, supply-chain governance, and strategic oversight, synergistic governance provides an analytically important mechanism for understanding how intelligent manufacturing may be translated into broader sustainability outcomes.

The stepwise regression results are reported in Table 3.23. Column (1) confirms that intelligent manufacturing exerts a positive and statistically significant effect on enterprise ESG performance. Column (2) shows that intelligent manufacturing also has a positive and statistically significant effect on synergistic governance, indicating that the implementation of intelligent manufacturing strengthens governance coordination rather than merely replacing conventional coordination arrangements. This result suggests that digital integration, real-time information sharing, and interconnection across operational systems can enhance the enterprise's ability to coordinate departments, processes, and stakeholder relationships in a more structured and responsive manner.

Column (3) incorporates both intelligent manufacturing and synergistic governance into the ESG regression. The coefficient on synergistic governance remains positive and statistically significant, while the coefficient on intelligent manufacturing decreases from 0.8032 to 0.7952 but remains significant. This pattern indicates that synergistic governance functions as a partial mediating mechanism in the relationship between intelligent manufacturing and enterprise ESG performance. In substantive terms, intelligent manufacturing contributes to ESG improvement not only directly, but also indirectly by strengthening cross-functional coordination, improving governance alignment, and enhancing the enterprise's capacity to implement sustainability-related objectives in an integrated way.

Table 3.23 Mediation Analysis: Synergistic Governance

	(1) ESG	(2) DEM	(3) ESG
IM	0.8032**	0.0456**	0.7952**
	(2.36)	(2.53)	(2.34)
SIZE	0.2301***	0.0025**	0.2297***
	(16.68)	(2.05)	(16.65)
LEV	-0.9527***	-0.0005	-0.9526***
	(-18.04)	(-0.11)	(-18.04)
ROA	-0.0519	0.3951***	-0.1211
	(-0.74)	(64.28)	(-1.60)
Top1	0.0170	0.0090	0.0154
	(0.18)	(1.09)	(0.16)
Age	-0.1335	-0.0006	-0.1334
	(-1.06)	(-0.06)	(-1.06)
SOE	0.0043	-0.0031	0.0048
	(0.13)	(-1.10)	(0.15)
DEM			0.1750**
			(2.45)
Year	Yes	Yes	Yes
Firm	Yes	Yes	Yes
_cons	-0.1191	-0.0683*	-0.1072
	(-0.26)	(-1.68)	(-0.23)
N	30347	30347	30347
adj. R^2	0.489	0.218	0.489

Source: Developed by the author

Notes: The dependent variables are ESG performance and synergistic governance (DEM). IM denotes intelligent manufacturing. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

To further verify the mediation effect, this dissertation supplements the Sobel-Goodman tests with bootstrap estimation. As reported in Table 3.24, the Sobel-Goodman results confirm that the indirect effect of intelligent manufacturing on enterprise ESG performance through synergistic governance is positive and statistically significant. The bootstrap results shown in Table 3.25 further support this finding. The estimated indirect effect is positive, and its 95% bootstrap confidence interval excludes zero, which indicates that the mediating role of synergistic governance remains statistically significant under repeated resampling. Meanwhile, the direct effect of intelligent manufacturing remains positive and statistically significant after the inclusion of synergistic governance, suggesting a partial mediation pattern. Therefore, the evidence consistently indicates that intelligent manufacturing contributes to enterprise ESG performance not only through direct technological and organizational upgrading, but also indirectly by strengthening governance coordination and execution capacity.

Table 3.24 Sobel-Goodman Tests for the Mediating Effect of Synergistic Governance

Test	Coefficient	Std.Error	Z-statistic	p-value
Sobel test	0.02121287	0.00989749	2.143	0.03209248
Goodman-1 (Aroian)	0.02121287	0.00996929	2.128	0.03335194
Goodman-2	0.02121287	0.00982517	2.159	0.03084756
Effect decomposition				
Indirect effect	0.021213	0.009897	2.14326	0.032092
Direct effect	2.667007	0.209359	12.9415	0.000
Total effect	2.68822	0.209556	12.8282	0.000
Proportion mediated	0.00789105			

Source: Developed by the author

Notes: This table reports Sobel and Goodman tests for the mediating effect of synergistic governance. Indirect, direct, and total effects are calculated based on the mediation framework. Z-statistics and corresponding p-values are reported.

Table 3.25 Bootstrap Test for the Mediating Effect of Synergistic Governance

Effect	Coefficient	Bootstrap Std.Err.	Z-statistic	p-value	95% Bootstrap Confidence Interval
Indirect effect	0.017912	0.006516	2.75	0.006	[0.005695, 0.030746]
Direct effect	0.846761	0.201441	2.87	<0.05	[0.282143,1.186286]

Source: Developed by the author

Notes: This table reports bootstrap estimates for the indirect and direct effects of intelligent manufacturing on enterprise ESG performance through synergistic governance. The bias-corrected (BC) 95% bootstrap confidence interval is reported. A mediating effect is considered statistically significant when the bootstrap confidence interval does not include zero.

3.6.5 Mechanism Analysis Summary

This dissertation conducts a comprehensive mechanism analysis to further elucidate how intelligent manufacturing influences enterprise ESG performance. By integrating multiple mediating channels, the findings reveal that the impact of intelligent manufacturing on ESG performance is transmitted through several distinct but interrelated pathways, reflecting different economic functions and organizational processes.

First, information transparency represents an information-environment channel. Intelligent manufacturing strengthens data collection, process traceability, and disclosure credibility, thereby reducing information asymmetry between the enterprise and external stakeholders. A more transparent informational environment improves external monitoring, enhances accountability, and creates stronger conditions for substantive ESG improvement.

Second, green technological innovation constitutes an innovation-capability channel. Through deeper integration of digital technologies, process optimization, and intelligent control systems, enterprises are better able to identify, test, and scale environmentally oriented innovations. In this way, intelligent manufacturing not only improves production efficiency, but also provides the organizational and technological basis for more continuous and implementable green innovation.

Third, financing constraints form an important resource-support channel in the realization of ESG gains. Intelligent transformation often requires substantial investment and sustained adjustment, which means that the financial feasibility of ESG related action remains highly relevant. The empirical results indicate that intelligent manufacturing can affect enterprise ESG performance in part by easing financing constraints and improving the conditions for sustained sustainability investment.

The information transparency channel and the financing-constraint channel should also be interpreted as mutually connected. Improved transparency reduces uncertainty and strengthens the credibility of firms' intelligent transformation and ESG commitments, which may improve external credit recognition and financing accessibility. However, financing conditions determine whether this credibility can be converted into continuous ESG related investment. Therefore, these two mechanisms reflect a sequential logic: information transparency improves the credibility of transformation, while the alleviation of financing constraints determines whether such credibility can become stable resource support for ESG improvement.

Fourth, synergistic governance represents an organizational-coordination channel. The mediation results show that synergistic governance exerts a positive and statistically significant mediating effect. This finding indicates that intelligent manufacturing can improve ESG performance by strengthening coordination across departments, processes, supply-chain relationships, and governance levels. In other words, the governance value of intelligent manufacturing lies not only in stronger monitoring or control, but also in its capacity to connect operational systems with broader organizational and stakeholder coordination. This finding also helps clarify how internal governance tensions during intelligent transformation are managed. Intelligent manufacturing changes not only production technologies, but also information flows, resource allocation, departmental responsibilities, and performance evaluation standards. These changes may create tensions among efficiency-oriented production goals, cost-control requirements, environmental compliance, and long-term ESG commitments. The role of synergistic governance is therefore to convert such tensions from fragmented departmental conflicts into coordinated decision-making. In this sense, internal conflict management is not a separate mechanism outside the model, but a concrete organizational function of the synergistic governance channel.

Taken together, the mechanism analysis demonstrates that intelligent manufacturing influences enterprise ESG performance through several coexisting and mutually reinforcing pathways. Its ESG effects arise from a combination of better information conditions, stronger green innovation, improved financing conditions for sustainability investment, and more integrated governance coordination. The mediation evidence is further strengthened by Sobel-Goodman tests and bootstrap estimation, both of which provide additional support for the statistical significance of the identified indirect effects. This multidimensional interpretation provides a more complete explanation of why intelligent manufacturing matters for sustainable corporate development and extends the analysis beyond a narrow efficiency-based understanding of technological upgrading. This interpretation is also consistent with the measurement logic of intelligent manufacturing adopted in this dissertation. The intelligent manufacturing index does not simply indicate whether a firm has introduced intelligent technologies. Rather, it reflects the firm's ability to transform intelligent-manufacturing-related capital and labor inputs into effective operating output. Therefore, the efficiency logic in this study should be understood as an operational foundation for ESG improvement, rather than as an independent mechanism separated from the four mediating channels. The mechanism analysis also indicates that intelligent manufacturing contributes to ESG performance through more than a direct efficiency-enhancing effect. Improvements in productivity, resource utilization, process traceability, and operational control need to be translated into ESG outcomes through information transparency, green technological innovation, financing support, and synergistic governance. In this sense, the four mediating mechanisms explain how operational efficiency is converted into environmental improvement, social responsibility fulfillment, and governance upgrading.

3.7 Heterogeneity Analysis

3.7.1 Heterogeneity Analysis: Western vs. Non-Western Regions

China exhibits pronounced regional disparities in terms of economic development, marketization level, institutional quality, and resource allocation efficiency. Among these, the distinction between Western regions and non-Western regions (including Eastern and Central China) is particularly salient and has been widely adopted in the literature on corporate governance and institutional economics (Fan et al., 2011; Lu & Yao, 2009).

From the perspective of Institutional Theory, regional differences in formal institutions, such as regulatory enforcement, information disclosure requirements, and legal protection, as well as informal institutions, such as governance norms and social monitoring, may fundamentally shape enterprises' responses to external governance pressures. Meanwhile, according to the Resource-Based View, enterprises' ability to transform governance incentives into substantive ESG outcomes depends critically on the availability of financial, technological, and managerial resources, which vary substantially across regions.

Consequently, dividing the sample into Western and non-Western regions allows for a more nuanced examination of whether and how the effect of intelligent manufacturing on enterprise ESG performance is contingent upon regional institutional environments and resource endowments. This distinction is substantively meaningful because regional variation in industrial foundations, institutional support, digital infrastructure, and market discipline may influence whether intelligent upgrading can be translated into credible ESG outcomes.

Table 3.26 presents the regression results for the regional heterogeneity analysis based on enterprises' registered locations. For enterprises located in non-Western regions, the coefficient on IM is positive and statistically significant at the 5% level ($\beta = 0.8497$, $t = 2.40$). This finding indicates that IM exerts a significantly positive effect on enterprise ESG performance in regions characterized by higher marketization and more developed institutional frameworks. This result is strongly consistent with Institutional Theory, which suggests that in regions with more effective regulatory enforcement and capital market supervision, governance mechanisms such as intelligent manufacturing are more likely to be internalized by enterprises and translated into substantive ESG engagement in order to gain legitimacy and conform to institutional expectations (DiMaggio & Powell, 1983). From the Resource-Based View, enterprises in non-Western regions typically possess stronger financial capacity, superior technological infrastructure, and more advanced governance systems, enabling them to convert external governance pressure into long-term ESG related capabilities and strategic investments.

In contrast, for enterprises located in Western regions, the coefficient on IM remains positive but is statistically insignificant ($\beta = 0.5351$, $t = 0.45$). This suggests that the positive impact of IM on enterprise ESG performance is substantially weakened in regions with relatively underdeveloped institutional environments. Two mechanisms may explain this result. First, weaker institutional enforcement and lower levels of market discipline in Western regions may dilute the effectiveness of IM as an external governance mechanism. Second, enterprises in these regions often face tighter resource constraints, which limit their capacity to respond to governance pressure through costly ESG investments, even when such pressure is perceived. This finding aligns with prior studies documenting the moderating role of regional institutional quality in shaping enterprise behavior in China (Cull & Xu, 2005; Zhang et al., 2020).

The weaker result in Western regions can therefore be understood in terms of lower conversion efficiency rather than the absence of technological potential. First, intelligent manufacturing in these regions may remain more concentrated on production modernization and efficiency enhancement, without yet being fully connected to ESG relevant governance arrangements such as environmental data systems, disclosure quality, stakeholder communication, and supply-chain sustainability coordination. Second, because intelligent transformation is capital-intensive and organizationally demanding, enterprises in Western regions may face tighter financial, technical, and managerial constraints in sustaining the follow-up investments needed to convert intelligent upgrading into broader ESG gains. Third, the external evaluation environment may itself be less conducive to such conversion. Where analyst coverage, market monitoring, regulatory scrutiny, and ESG related institutional pressure are relatively weaker, even genuine improvements in internal operations may be reflected in ESG performance only slowly or incompletely.

With respect to control variables, firm size (SIZE) and leverage (LEV) exhibit consistent signs and strong statistical significance across both sub-samples, indicating that basic firm characteristics exert a robust influence on ESG performance regardless of regional context. However, firm age (Age) shows a significantly negative effect in the Western sub-sample, reflecting the structural disadvantages faced by older enterprises in less developed regions in terms of organizational adaptability and governance modernization.

Overall, the regional heterogeneity analysis demonstrates that the effect of IM on corporate ESG performance is highly context-dependent. Specifically, IM significantly enhances ESG performance in non-Western regions with stronger institutional environments and richer resource endowments, while its impact is considerably weaker in Western regions. These findings provide further empirical support for the contingent nature of governance mechanisms emphasized by Institutional Theory and underscore the importance of regional resource heterogeneity highlighted by the Resource-Based View. They also suggest that policy interventions aimed at improving ESG outcomes should account for regional disparities in institutional development and resource availability.

Table 3.26 Heterogeneity Analysis: Western vs. Non-Western Regions

	(Western)	(Non-Western)

	ESG	ESG
IM	0.5351	0.8497**
	(0.45)	(2.40)
SIZE	0.2386***	0.2293***
	(6.28)	(15.31)
LEV	-0.9304***	-0.9340***
	(-6.09)	(-16.46)
ROA	0.0369	-0.0709
	(0.17)	(-0.95)
Top1	-0.1738	0.0437
	(-0.71)	(0.42)
Age	-1.0535***	-0.0067
	(-2.74)	(-0.05)
SOE	0.0570	0.0102
	(0.55)	(0.30)
Year	Yes	Yes
Firm	Yes	Yes
_cons	2.3360	-0.4738
	(1.63)	(-0.96)
N	3652	26695
adj. R^2	0.521	0.481

Source: Developed by the author

Notes: This table reports the heterogeneous effects of IM on enterprises' ESG performance across Western and non-Western regions in China. Regional classification follows the official regional division. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

3.7.2 Heterogeneity Analysis: High-Tech vs. Non-High-Tech Enterprise

Enterprises differ substantially in their technological intensity, innovation capacity, and strategic orientation toward long-term value creation. These differences are not only firm-level characteristics, but are also closely embedded in the sectoral contexts in which enterprises operate. In the Chinese context, the distinction between high-tech enterprises and non-high-tech enterprises is particularly meaningful, as high-tech enterprises are officially certified based on strict criteria related to R&D intensity, technological capabilities, and innovation outputs. This classification has been widely adopted in studies examining corporate innovation, governance mechanisms, and sustainability performance (Hall & Lerner, 2010; Zhang et al., 2021).

From the perspective of the Resource Based View (RBV), high-tech enterprises typically possess stronger intangible assets, such as technological knowledge, human capital, and dynamic capabilities, which enable them to better absorb intelligent manufacturing technologies and convert them into green innovation, process transparency, and governance improvement. In contrast, non-high-tech enterprises often rely more heavily on traditional production factors and may face tighter constraints in reallocating resources toward ESG related investments. This means that the ESG effect of intelligent manufacturing may depend not only on whether intelligent manufacturing is adopted, but also on whether the technological and sectoral conditions of the enterprise support the conversion of intelligent manufacturing into substantive ESG outcomes.

Meanwhile, Institutional Theory suggests that enterprises operating in innovation-intensive sectors are subject to stronger normative and mimetic pressures, as stakeholders, including regulators, investors, and the public, tend to hold higher expectations regarding their social and environmental responsibilities. Accordingly, the governance effect of intelligent manufacturing on ESG performance may vary systematically depending on whether a firm operates as a high-tech enterprise or a non-high-tech enterprise.

Based on these considerations, this dissertation further examines the heterogeneity of IM's impact on ESG performance by distinguishing between high-tech and non-high-tech enterprises.

Table 3.27 reports the regression results for the sub-samples of high-tech and non-high-tech enterprises.

For high-tech enterprises, the coefficient on IM is positive and statistically significant at the 5% level ($\beta = 0.8235$, $t = 2.22$). This result indicates that IM plays a significant role in promoting ESG performance among enterprises with strong technological and innovative capabilities. This finding is consistent with the Resource-Based View, as high-tech enterprises are better positioned to transform governance pressure induced by IM into ESG related investments and strategic actions. Their superior R&D capacity, flexible organizational structures, and long-term orientation facilitate the internalization of ESG objectives into innovation-driven business models. Moreover, from an Institutional Theory perspective, high-tech enterprises often face heightened legitimacy pressures, as they are perceived as industry leaders and innovation pioneers. As a result, IM exerts a stronger disciplinary and signaling effect, encouraging these enterprises to actively enhance ESG performance to meet stakeholder expectations and maintain reputational advantages.

In contrast, for non-high-tech enterprises, the coefficient on IM is negative but statistically insignificant ($\beta = -0.0753$, $t = -0.08$), suggesting that IM does not exert a meaningful influence on ESG performance in this group. This result implies that in enterprises with lower technological intensity and weaker innovation capacity, the governance incentives associated with IM are less likely to be translated into substantive ESG improvements. Resource constraints, limited absorptive capacity, and a stronger focus on short-term operational efficiency may hinder non-high-tech enterprises from responding effectively to external governance pressure through ESG engagement.

Overall, the heterogeneity analysis reveals that the effect of IM on ESG performance is significantly stronger among high-tech enterprises, while it is negligible for non-high-tech enterprises. This pattern indicates that the ESG consequences of intelligent manufacturing are shaped by enterprises' technological foundations, absorptive capacity, and sectoral production conditions. These findings reinforce the argument that IM functions not merely as an external governance device but as a capability-contingent mechanism, whose effectiveness depends on enterprises' internal resource endowments and strategic orientation. By integrating insights from Institutional Theory and the Resource-Based View, this analysis provides a more comprehensive understanding of why governance mechanisms generate heterogeneous ESG outcomes across different types of enterprises.

Table 3.27 Heterogeneity Analysis: High-Tech vs. Non-High-Tech Enterprise

	(High-Tech Enterprise)	(Non-High-Tech Enterprise)
	ESG	ESG
IM	0.8235**	-0.0753
	(2.22)	(-0.08)
SIZE	0.2238***	0.2066***
	(12.40)	(8.77)
LEV	-1.0317***	-0.7458***
	(-15.23)	(-8.32)
ROA	-0.1655*	0.1162
	(-1.90)	(0.92)
Top1	0.0668	-0.0069
	(0.53)	(-0.04)
Age	-0.3477**	0.0731
	(-2.12)	(0.36)
SOE	0.0910**	-0.1698***
	(2.24)	(-3.11)
Year	Yes	Yes
Firm	Yes	Yes
_cons	0.6761	-0.2507
	(1.13)	(-0.32)
N	18897	11450
adj. R^2	0.474	0.522

Source: Developed by the author

Notes: This table reports the heterogeneous effects of IM on enterprises' ESG performance by distinguishing between high-tech and non-high-tech enterprises. High-tech enterprise classification follows official certification standards in China. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

3.7.3 Heterogeneity Analysis: Shanghai & Shenzhen A-Share Listed Companies vs. Beijing A-Share Listed Companies

China's multi-tier capital market structure provides a unique institutional setting in which companies listed on different exchanges are subject to distinct regulatory regimes, investor bases, and market expectations. In particular, companies listed on the Shanghai and Shenzhen A-share markets differ markedly from those listed on the Beijing Stock Exchange (BSE) in terms of firm size, maturity, innovation orientation, and governance environments.

The Shanghai and Shenzhen A-share markets are characterized by higher liquidity, broader institutional investor participation, stricter disclosure requirements, and more intense external monitoring. By contrast, the Beijing Stock Exchange, established to serve innovative small and medium-sized enterprises (SME), features a more concentrated investor structure, relatively lower market visibility, and a regulatory framework that places greater emphasis on growth potential rather than comprehensive ESG performance (Allen et al., 2019; CSRC, 2021).

From the perspective of Institutional Theory, these differences imply heterogeneous institutional pressures across listing venues, which may condition how enterprises respond to governance mechanisms such as intelligent manufacturing. Meanwhile, the Resource-Based View suggests that firms listed on Shanghai and Shenzhen exchanges generally possess stronger resource endowments, financial, organizational, and reputational, enabling them to translate governance incentives into ESG investments more effectively.

Accordingly, distinguishing between Shanghai & Shenzhen A-share companies and Beijing A-share companies provides a meaningful lens to examine the context-dependent effects of IM on ESG performance.

The results in Table 3.28 show clear listing-board heterogeneity in the ESG effect of intelligent manufacturing. For firms listed on the Shanghai and Shenzhen A-share markets, the coefficient on IM is positive and statistically significant at the 5% level ($\beta = 0.8098$, $t = 2.37$), indicating that intelligent manufacturing contributes more effectively to ESG improvement in these markets. This finding is consistent with the expectation that firms operating in more mature capital-market environments are subject to stronger governance norms, disclosure requirements, and external monitoring, which facilitate the translation of intelligent manufacturing into observable ESG performance. Meanwhile, this finding aligns closely with Institutional Theory, as companies in these markets face stronger coercive and normative pressures from regulators, institutional investors, analysts, and the media. Under such conditions, IM functions as an effective governance mechanism that incentivizes enterprises to improve ESG performance to maintain legitimacy and market credibility. From a Resource-Based View, companies listed on Shanghai and Shenzhen exchanges typically exhibit greater financial slack, more mature governance structures, and stronger reputational concerns, allowing them to respond proactively to IM induced governance pressure through substantive ESG engagement.

In contrast, for companies listed on the Beijing Stock Exchange, the coefficient on IM is negative but statistically insignificant ($\beta = -2.7424$, $t = -0.71$), indicating that the ESG effect of intelligent manufacturing is not empirically established in this sub-sample. A more plausible explanation lies in the characteristics of Beijing Stock Exchange firms and the market environment in which they operate. The Beijing Stock Exchange mainly serves innovative small and medium-sized enterprises, many of which remain in a relatively resource-constrained and growth-oriented stage. Under such conditions, intelligent manufacturing is more likely to be directed toward technological upgrading, production improvement, and market expansion, while its transformation into broader ESG outcomes may require stronger organizational support, longer adjustment periods, and more mature governance arrangements. At the same time, compared with firms listed on the Shanghai and Shenzhen exchanges, Beijing Stock Exchange firms generally face lower market visibility and relatively weaker external monitoring in ESG related areas, which may reduce the extent to which intelligent manufacturing is converted into observable improvements in disclosure quality, stakeholder responsiveness, and governance performance. In addition, the much smaller size of the Beijing Stock Exchange sub-sample may also make stable statistical effects more difficult to identify. Therefore, the insignificant result is more appropriately understood as reflecting a weaker or not yet fully realized ESG effect of intelligent manufacturing in this segment.

Overall, the listing-venue heterogeneity analysis reveals that the positive effect of IM on ESG performance is concentrated among companies listed on the Shanghai and Shenzhen A-share markets, while it is absent among Beijing A-share listed companies. This finding underscores the importance of capital market institutions in shaping the effectiveness of governance mechanisms. These results further reinforce the central argument of this dissertation: the impact of IM on ESG performance is institutionally contingent and resource-dependent. IM operates more effectively in environments characterized by stronger market discipline, higher transparency, and richer resource endowments, consistent with predictions from Institutional Theory and the Resource-Based View.

Table 3.28 Heterogeneity Analysis: Shanghai & Shenzhen A-Share Listed Companies vs. Beijing A-Share Listed Companies

	(Shanghai & Shenzhen A-Share Listed Companies)	(Beijing A-Share Listed Companies)
	ESG	ESG
IM	0.8098**	-2.7424
	(2.37)	(-0.71)
SIZE	0.2303***	0.0722
	(16.65)	(0.30)
LEV	-0.9563***	0.3477
	(-18.04)	(0.62)
ROA	-0.0520	-0.0206
	(-0.74)	(-0.02)
Top1	0.0193	-1.2650
	(0.20)	(-1.17)
Age	-0.1329	0.2162
	(-1.05)	(0.11)
SOE	0.0045	0.0000
	(0.14)	(.)
Year	Yes	Yes
Firm	Yes	Yes
_cons	-0.1256	2.3750
	(-0.27)	(0.31)
N	30068	279
adj. R^2	0.489	0.589

Source: Developed by the author

Notes: This table reports heterogeneous effects of IM on enterprises' ESG performance across different listing venues. The sample is divided into Shanghai & Shenzhen A-share listed companies and Beijing A-share listed companies. Firm and year fixed effects are included in all regressions. t-statistics are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

3.7.4 Summary of Heterogeneity Analysis

Rather than reiterating specific sub-sample results, the heterogeneity analyses collectively reveal a systematic pattern regarding the conditional effectiveness of intelligent manufacturing as a governance mechanism. The heterogeneity analysis shows that the effect of intelligent manufacturing on enterprise ESG performance is not uniform across enterprises, but varies systematically with regional institutional conditions, technological capability, and capital-market environment. In all three dimensions, the results point to the same broader conclusion: the ESG consequences of intelligent manufacturing depend not only on the adoption of intelligent technologies, but also on whether enterprises operate under institutional arrangements and economic conditions that enable intelligent upgrading to be translated into sustained organizational and sustainability outcomes. More specifically, from an institutional perspective, stronger regulatory enforcement, disclosure norms, stakeholder scrutiny, and market monitoring increase the likelihood that intelligent manufacturing will be internalized as a governance-relevant practice rather than remain confined to operational modernization. From an economic perspective, stronger resource endowments, higher absorptive capacity, better digital infrastructure, and greater strategic flexibility improve enterprise's ability to connect intelligent transformation with green innovation, governance coordination, and broader ESG implementation. This pattern is also reflected in the insignificant result for Beijing Stock Exchange firms, which suggests that for smaller and innovation-oriented enterprises operating under relatively tighter resource constraints and less mature market discipline, intelligent manufacturing may improve operational capability without necessarily being translated into immediate and statistically observable ESG gains.

Importantly, these findings indicate that intelligent manufacturing should not be interpreted as a universally effective governance tool. Instead, its influence on ESG outcomes is contingent, context-sensitive, and capability-dependent. This insight advances existing ESG governance literature by moving beyond average effects and highlighting the necessity of incorporating both institutional heterogeneity and firm-level resource heterogeneity into the analysis of governance mechanisms.

From a theoretical perspective, the heterogeneity evidence reinforces the complementary roles of Institutional Theory and the Resource-Based View developed in Chapter 1. Institutional Theory explains how variations in regulatory environments, market scrutiny, and legitimacy pressures shape enterprises' incentives to respond to intelligent manufacturing, while the Resource-Based View clarifies why only enterprises with adequate internal resources and dynamic capabilities are able to convert such incentives into substantive ESG improvements.

Overall, the heterogeneity results deepen the interpretation of the baseline findings by showing that intelligent manufacturing should be understood as a context-dependent driver of enterprise ESG performance. Its sustainability effects are more likely to be realized when technological transformation is matched by supportive institutions, stronger capability endowments, and more mature market environments.

The heterogeneity results can be further understood through the interaction between information transparency and financing constraints. In high-tech enterprises and enterprises operating in more mature market environments, intelligent manufacturing is more likely to improve process visibility, disclosure credibility, and external recognition, and these informational improvements are more likely to be converted into financing support and ESG investment. By contrast, in non-high-tech enterprises and enterprises facing weaker external support, intelligent transformation may initially increase capital expenditure, adjustment costs, and managerial pressure. If financing constraints are not eased accordingly, the positive information effect generated by intelligent manufacturing may be weakened, delayed, or partly offset by resource pressure. This explains why the ESG enhancing effect of intelligent manufacturing may vary across industries and enterprise contexts.

3.8 Qualitative Case Analysis and Discussion

3.8.1 Case Selection and Research Design

The qualitative analysis in this dissertation adopts a multiple-case study design to complement the econometric results reported in the preceding sections. Its purpose is not to provide additional statistical verification, but to clarify the organizational processes through which intelligent manufacturing is translated into enterprise ESG outcomes in concrete enterprise settings. For this reason, the case selection follows a logic of theoretical sampling, with the aim of identifying information-rich cases that offer the greatest explanatory leverage for mechanism interpretation.

More specifically, the four case enterprises were selected according to a fourfold criterion. First, each case had to demonstrate a substantive and visible intelligent-manufacturing transformation, rather than isolated automation upgrades or symbolic digital initiatives. This criterion ensures that the selected enterprises reflect intelligent manufacturing as a broader organizational reconfiguration involving production systems, data architecture, operational coordination, and managerial processes. Second, each case had to exhibit a clear analytical fit with one of the mediating mechanisms identified in the quantitative analysis. The case design is therefore mechanism-oriented rather than merely illustrative. Third, the selected enterprises needed to possess high demonstrative value within their industries, so that the case evidence would reveal not only enterprise-specific practices but also broader patterns of organizational transformation in advanced Chinese manufacturing. Fourth, the cases had to satisfy the requirement of data sufficiency and cross-source verifiability, meaning that their intelligent-manufacturing practices and ESG related developments could be traced through annual reports, ESG or sustainability reports, official corporate disclosures, industrial reports, and other authoritative public materials.

Based on these criteria, four Chinese listed companies, Haier Smart Home, Midea Group, Contemporary Amperex Technology Co., Limited (CATL), and Seres, were selected. These enterprises operate in different manufacturing sub-sectors, yet they are comparable in three important respects: all are manufacturing-oriented listed enterprises, all have pursued relatively deep intelligent transformation, and all provide sufficiently rich documentary evidence for case reconstruction. More importantly, each case is linked to a different analytical mechanism identified in the quantitative section: Haier is used to examine the information-transparency mechanism, Midea the green technological innovation mechanism, CATL the financing-constraints mechanism, and Seres the synergistic-governance mechanism.

It should also be emphasized that the selection of these enterprises is not intended to claim that they are statistically representative of all Chinese manufacturing enterprises, nor to suggest that only highly successful enterprises can illuminate the relationship between intelligent manufacturing and enterprise ESG performance. In a mixed-methods design of this kind, the function of case selection is analytical generalization rather than population inference. The reason for choosing enterprises with relatively visible transformation trajectories is that such cases make the underlying organizational processes more observable, the evidence more verifiable, and the mechanism tracing more reliable. Accordingly, the value of these cases lies not in their ability to mirror the full distribution of Chinese enterprises, but in their capacity to reveal how different mechanism channels operate under real organizational conditions.

The choice of these four enterprises should therefore be understood as an analytical design decision rather than a claim of broad statistical representativeness. Taken together, they form a replication-based case set: each case supports the broader proposition that intelligent manufacturing is associated with enterprise ESG performance, while each also illuminates a distinct pathway through which that relationship may unfold. This design strengthens the coherence between the qualitative and quantitative parts of the dissertation and allows the case evidence to function as a mechanism-oriented extension of the regression results.

3.8.2 Intelligent Manufacturing and Information Transparency: Case Evidence

To supplement the quantitative evidence on the mediating role of information transparency, this section examines Haier Smart Home as the focal case for this mechanism. Haier was selected not merely because of its industrial prominence, but because its intelligent-manufacturing transformation offers an especially clear illustration of how production digitalization can reshape the internal generation, circulation, and verification of firm-level information. Built around the COSMOPlat industrial internet platform and supported by integrated systems covering procurement, production, quality control, logistics, and energy management, Haier's transformation extends beyond equipment upgrading to the reorganization of the enterprise's information structure. This makes the case particularly suitable for examining whether intelligent manufacturing improves enterprise ESG performance by enhancing the visibility, traceability, and credibility of operational information

The analytical value of the Haier case lies in the fact that its intelligent manufacturing practices are directly connected with the generation and circulation of operational information. In traditional manufacturing enterprises, information related to production progress, equipment status, quality inspection, and resource consumption is often dispersed across workshops and departments, updated with delay, and heavily dependent on manual reporting. Under such conditions, even if enterprises disclose ESG information externally, the underlying data foundation may remain weak. Haier's practice differs in that it embeds data collection, process monitoring, and system connectivity into the production process itself. Once the production system becomes digitally connected, information transparency is no longer limited to disclosure at the reporting stage; it is produced continuously during operation. This is the key point at which intelligent manufacturing becomes relevant to ESG performance.

In Haier's case, the most important practical basis for this mechanism is the COSMOPlat platform. As an industrial IoT platform, COSMOPlat, boasts of independent intellectual property rights in China and full-process user engagement. In accordance with the philosophy of mutual evolution and value sharing, COSMOPlat embraces innovations in mass customization models, the fusion of information technology and manufacturing technology and the microenterprise mechanism in different industries. In this way, COSMOPlat will be a platform that empowers interactions and value sharing, breeds new species, and supports entrepreneurs and innovations. COSMOPlat was developed by Haier as an industrial internet platform and later became one of the national benchmark platforms for industrial internet-based smart manufacturing in China. What matters for the present study is not the platform label itself, but the way it changes the information structure of manufacturing. By linking design, procurement, production, logistics, and user-side demand into one digital system, COSMOPlat reduces the separation between operational execution and information feedback. Information that would otherwise remain fragmented at different nodes can be captured, transmitted, and updated within the same digital architecture. As a result, the firm gains stronger visibility over production processes, and the traceability of operational information is significantly improved. For a manufacturing enterprise, this constitutes the most substantive foundation of information transparency.

Figure 3.2 User-Centered Ecosystem Logic of Intelligent Manufacturing: The Haier Case

Source: official website of Haier

Figure 3.2 presents the user-centered ecosystem logic underlying Haier's intelligent manufacturing transformation. The figure highlights how the enterprise moves beyond a traditional firm-centered production model by establishing a zero-distance connection among users, corporate operations, and external resources. Through this ecosystem logic, intelligent manufacturing supports the dynamic orchestration of resources, model transformation, and the simultaneous improvement of quality and efficiency. The figure suggests that the value of intelligent manufacturing lies not only in process automation or operational optimization, but also in its ability to reorganize the enterprise around user demand and ecosystem collaboration. This perspective provides an additional interpretive lens for understanding how intelligent manufacturing can enhance enterprise sustainability and long-term value creation.

This transparency effect can be observed clearly in Haier's production and quality management practices. Haier's intelligent manufacturing system allows production progress, equipment operation, and product quality to be monitored in real time rather than checked only after production is completed. This changes the enterprise's control logic from ex post inspection to process-based monitoring. From the standpoint of case analysis, the significance of this shift is twofold. On the one hand, it reduces the loss and distortion of information during internal transmission, because production data are generated automatically and shared through the platform. On the other hand, it strengthens the verifiability of product-related information, because product performance and quality results can be traced back to specific production links. In ESG terms, this directly supports the social dimension of performance, especially in relation to product responsibility, consumer protection, and accountability for operational quality. An enterprise whose quality information is generated and retained through a traceable digital process is in a stronger position to make credible commitments to consumers and regulators than an enterprise relying on fragmented manual records.

The same logic is even more evident in environmental management. Haier has not treated environmental data as a separate reporting category outside production; instead, it has incorporated energy and carbon management into its intelligent manufacturing system. Its Haier Smart Energy Center functions as a digital energy and carbon management platform and carries out centralized dynamic monitoring of major energy consumption, including water, electricity, and gas, across plants. This practice is highly significant for the mechanism examined here. In many manufacturing firms, environmental disclosure is constrained by the weak measurability of environmental data at the plant level. Haier's approach reduces this problem by turning resource consumption into continuously monitored operational data. Once energy use is monitored dynamically rather than estimated retrospectively, environmental information becomes more accurate, more timely, and more comparable across production units. For ESG performance, the implication is straightforward: intelligent manufacturing improves environmental transparency at the data source, which makes environmental governance more substantive and external disclosure more credible.

The Haier case also shows that improved information transparency is not confined to the shop-floor level; it is transmitted upward into corporate governance. Haier's annual governance arrangements indicate that ESG information, financial reporting, internal control, and information disclosure are all reviewed within formal board committee structures. During 2024, the company held multiple Audit Committee meetings covering financial reporting and internal control, and three ESG Committee meetings covering the ESG report, ESG competency assessment, and ESG work progress. In addition, the company revised its Management System for Information Disclosure. From a case-analysis perspective, these arrangements matter because intelligent manufacturing only becomes an ESG enhancing mechanism when production-side data can be incorporated into governance-side decision-making. In Haier's case, digital manufacturing generates data; committee governance absorbs and reviews those data; and disclosure rules convert them into externally communicable information. The mechanism linking intelligent manufacturing to information transparency is therefore organizationally complete rather than merely technical.

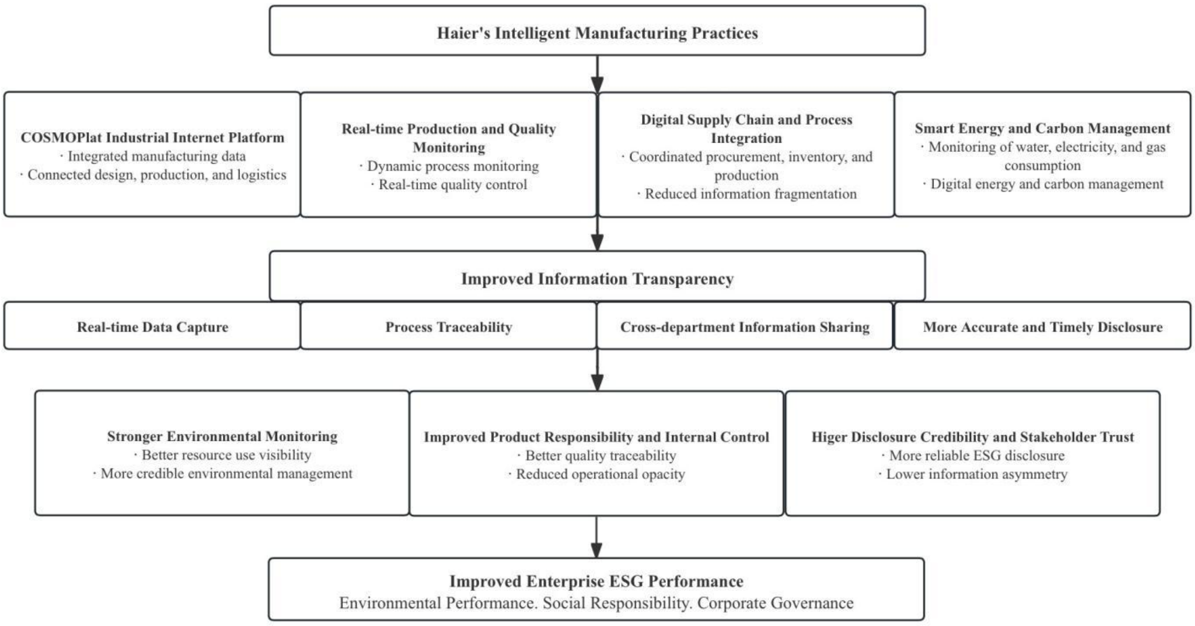
This internal transparency is further reflected in Haier's external communication with capital-market participants. The company states that, in addition to mandatory disclosure, it maintained voluntary disclosure on issues of concern to domestic and overseas investors, including strategy, investment and acquisition projects, and ESG, with the stated aim of improving the quality and transparency of disclosure. For the present case, the importance of this point does not lie in the disclosure statement itself, but in what makes such disclosure sustainable. Voluntary disclosure has limited value if the enterprise cannot continuously generate reliable underlying data. Haier's intelligent manufacturing system provides precisely this missing foundation. Because production, inventory, procurement, and energy data are increasingly digitalized and integrated, external disclosure is less dependent on selective narrative presentation and more closely tied to the firm's actual operating processes. This strengthens investor confidence in the authenticity of disclosed ESG information and lowers the informational gap between the firm and external stakeholders.

From the viewpoint of ESG outcomes, the Haier case suggests that the effect of information transparency operates through a concrete three-step mechanism. The first step is that intelligent manufacturing restructures the enterprise's information infrastructure by digitalizing production, quality, supply-chain, and energy-management processes. The second step is that this infrastructure improves the transparency of enterprise information by making it more real-time, traceable, and internally shareable. The third step is that better information transparency improves ESG performance by strengthening environmental monitoring, product and consumer accountability, internal control, and the credibility of external disclosure. This mechanism is visible in Haier's practice and corresponds closely to the logic of the empirical model developed earlier in this dissertation. In other words, the case does not merely show that Haier is good at ESG; it shows why intelligent manufacturing can create the informational conditions under which ESG performance becomes more measurable, more governable, and more credible.

The case also provides a plausible explanation for Haier's relatively strong ESG standing. Haier reports that it maintained leading ESG ratings among Chinese peers from major rating agencies and that its MSCI ESG rating reached AA. These outcomes should not be mechanically attributed to intelligent manufacturing alone, but they are consistent with the proposition advanced in this dissertation: when intelligent manufacturing improves the transparency of operational and governance information, firms are better able to convert internal management capability into externally recognized ESG performance. The role of information transparency here is therefore mediating rather than decorative. It connects intelligent manufacturing on the production side with ESG performance on the governance and stakeholder side.

On this basis, the Haier case offers clear qualitative support for the information-transparency mechanism. The evidence does not suggest that intelligent manufacturing improves ESG performance simply by raising efficiency. Rather, its more important function is that it reconstructs the firm's information environment. In Haier's practice, COSMOPlat, digital supply-chain management, real-time quality monitoring, and the Smart Energy Center jointly make operational information more visible and more traceable; board-level ESG and audit arrangements then convert this visibility into stronger governance and more credible disclosure. This is precisely the causal chain that the quantitative analysis identifies. The case therefore supports the conclusion that intelligent manufacturing can positively affect enterprise ESG performance through the mediating role of information transparency.

Figure 3.3 Haier Case: Information Transparency Mechanism Linking Intelligent Manufacturing and Enterprise ESG Performance



Source: Developed by the author

Figure 3.3 illustrates how Haier improves enterprise ESG performance through the mediating role of information transparency. Specifically, Haier's intelligent manufacturing practices, including the COSMOPlat industrial internet platform, real-time production and quality monitoring, digital supply chain integration, and smart energy management, enhance the timeliness, accuracy, traceability, and shareability of enterprise information. These changes improve information transparency, strengthen environmental monitoring, internal control, and disclosure credibility, and ultimately contribute to better ESG performance.

Overall, the Haier case provides strong process-based support for the information transparency mechanism proposed in the quantitative analysis. The case shows that intelligent manufacturing can improve not only the efficiency of information collection, but also the internal consistency and external credibility of ESG relevant information. At the same time, the case should not be interpreted as implying that information transparency is automatically generated once digital technologies are introduced. Its effectiveness still depends on the degree of system integration, managerial commitment, and the enterprise's ability to convert operational data into decision-useful information. In this sense, the case confirms the directional logic identified in the regression results while also clarifying an important boundary condition: intelligent manufacturing enhances ESG performance through information transparency only when data visibility is accompanied by organizational integration and effective information governance.

3.8.3 Intelligent Manufacturing and Green Technological Innovation: Case Evidence

To complement the quantitative evidence on the mediating role of green technological innovation, this section examines Midea Group as the focal case for this mechanism. Midea was selected because its intelligent-manufacturing transformation is analytically well matched to the innovation channel identified in the regression analysis. Rather than treating intelligent manufacturing as a narrow issue of production automation, Midea has embedded digital technologies into product development, process optimization, energy management, and logistics coordination, thereby creating conditions under which green innovation can be generated, tested, and scaled within the production system itself. Midea Group, a leading global technology group, provides a highly relevant empirical context for clarifying the green technological innovation mechanism through which intelligent manufacturing affects enterprise ESG performance. In China's manufacturing sector, Midea has moved intelligent manufacturing well beyond isolated automation or workshop-level digital upgrading. Its industrial internet platform M・IoT, the continuous expansion of lighthouse factories, and the embedding of digital systems into energy management, product development, and process optimization indicate that intelligent manufacturing has become an organizational capability connected with technological upgrading rather than a narrow production technology. By 2024, Midea had developed multiple global lighthouse factories, while M·IoT had been positioned as the company's industrial internet infrastructure for intelligent manufacturing and industrial interconnectivity. These practices make Midea particularly useful for illustrating how intelligent manufacturing can reshape the conditions under which green technological innovation is generated, implemented, and diffused.

The analytical significance of Midea lies not in innovation performance in a general sense, but in the way intelligent manufacturing changes the enterprise's innovation logic. In many manufacturing enterprises, green innovation remains detached from the production system. It may exist in R&D departments, pilot projects, or externally oriented sustainability programs, yet fail to alter day-to-day manufacturing practice in a sustained way. Midea's approach is different. Its digital manufacturing architecture links R&D, production execution, logistics, and supply-chain coordination within a connected platform environment. Once production data, equipment conditions, process parameters, and resource-consumption information are continuously generated and shared, technological problems that were previously hidden in fragmented operational processes become identifiable. Green innovation then becomes less dependent on broad environmental slogans and more dependent on specific, data-based opportunities for technical improvement. In this respect, intelligent manufacturing does not simply coexist with green innovation; it reorganizes the informational and operational conditions that make green innovation feasible.

A central feature of Midea's practice is the use of M·IoT as a cross-functional industrial internet platform. The importance of M·IoT for the present analysis is not merely that it digitalizes manufacturing, but that it reduces the distance between production-side problems and innovation-side responses. In a traditional manufacturing setting, excessive energy consumption, material loss, or inefficient process design may be observable only after aggregated reporting, by which time the feedback loop between technical diagnosis and process improvement has already weakened. Midea's platform-based manufacturing model changes this by integrating industrial software, digitalization services, and manufacturing interconnectivity into a common system. Under such conditions, energy-intensive links, process bottlenecks, and quality-related inefficiencies are more likely to be recognized in real time and translated into technical upgrading tasks. The platform therefore serves as the enabling infrastructure through which green process innovation can emerge from the production system itself.

This mechanism is especially visible in Midea's lighthouse factory practice. Lighthouse factories matter here not as symbols of digital prestige, but as organizational spaces in which intelligent manufacturing and green upgrading are jointly implemented. The logic is straightforward: once production is organized through real-time sensing, automated control, and dynamic optimization, the enterprise is able to identify where energy use is unnecessarily high, where process stability is weak, and where equipment scheduling produces avoidable waste. These observations create the technical basis for green process innovation. In other words, digitalization provides visibility; visibility enables diagnosis; and diagnosis supports targeted process redesign. Midea's multiple lighthouse factories therefore show that intelligent manufacturing can transform green innovation from a peripheral activity into an endogenous outcome of data-driven production management. The relevance to ESG performance is direct, because cleaner production and lower resource intensity improve the substantive basis of the environmental dimension of ESG.

Midea's energy-management practice further clarifies this pathway. The company has built digital energy-management systems capable of collecting plant-level data on electricity, water, gas, and related utility consumption through large-scale device connectivity. From a case-analysis perspective, the crucial point is not simply that the enterprise monitors energy use, but that energy data are turned into high-frequency operational information rather than retrospective summary statistics. This materially changes the way green innovation occurs. When energy consumption is observed only after the fact, the enterprise can set conservation targets but cannot easily identify which specific process links should be redesigned. By contrast, when energy data are continuously generated and tied to production processes, technical teams can identify abnormal consumption patterns, compare the performance of production units, and redesign process parameters or equipment configurations accordingly. Intelligent manufacturing thus lowers the information cost of green process innovation and makes environmental upgrading more precise, iterative, and operationally grounded.

The connection between intelligent manufacturing and green innovation in Midea is not limited to process improvement; it also extends to product-side technological upgrading. This is important because enterprise ESG performance depends not only on how enterprises manufacture, but also on what kinds of products they bring into the market. Midea's broader technology strategy has combined intelligent transformation with energy-saving, low-carbon development, and product innovation. Once digital manufacturing systems connect product design, testing, and manufacturing execution, green product innovation becomes easier to implement at scale. New energy-saving designs can be tested against actual manufacturing conditions, adjusted on the basis of production feedback, and then replicated across product lines with greater consistency. This reduces the gap between product-level environmental ambition and manufacturable technical reality. In practical terms, intelligent manufacturing strengthens the enterprise's ability to produce greener appliances with lower lifecycle environmental burdens, thereby linking internal technological capability with the environmental and social dimensions of ESG.

Another important feature of Midea's practice is the standardization and diffusion of technical improvements. For large manufacturing groups, isolated technological breakthroughs do not automatically improve ESG performance. The ESG effect of green innovation depends on whether technical solutions can be codified, replicated, and embedded in routine production systems. Midea's intelligent manufacturing architecture supports this process by creating common digital interfaces, measurable process indicators, and standardized production parameters across factories. Once a lower-carbon process solution or a more energy-efficient technical configuration proves effective in one manufacturing setting, digital platforms make it easier to transfer that solution to other units. This gives green innovation a cumulative character. Rather than remaining a collection of separate pilot projects, it becomes a repeatable production capability. That organizational property is crucial for explaining why intelligent manufacturing can have a sustained rather than temporary effect on ESG performance.

The innovation system surrounding Midea's intelligent transformation also reinforces this interpretation. The company has paired digital manufacturing expansion with a stronger emphasis on patents, standards, and the industrialization of technical knowledge. From the standpoint of case analysis, the importance of patents and standards lies not in counting innovative outputs mechanically, but in showing that the enterprise is capable of repeatedly generating, protecting, and institutionalizing technical solutions. Green technological innovation becomes more consequential for ESG when it is not merely invented but incorporated into a structured system of production and quality management. Midea's efforts to integrate innovation, standards, and industrial deployment suggest that intelligent manufacturing is embedded in a broader capability structure that supports the sustained development and application of low-carbon and energy-saving technologies. This makes the green-innovation mechanism more credible at the enterprise level.

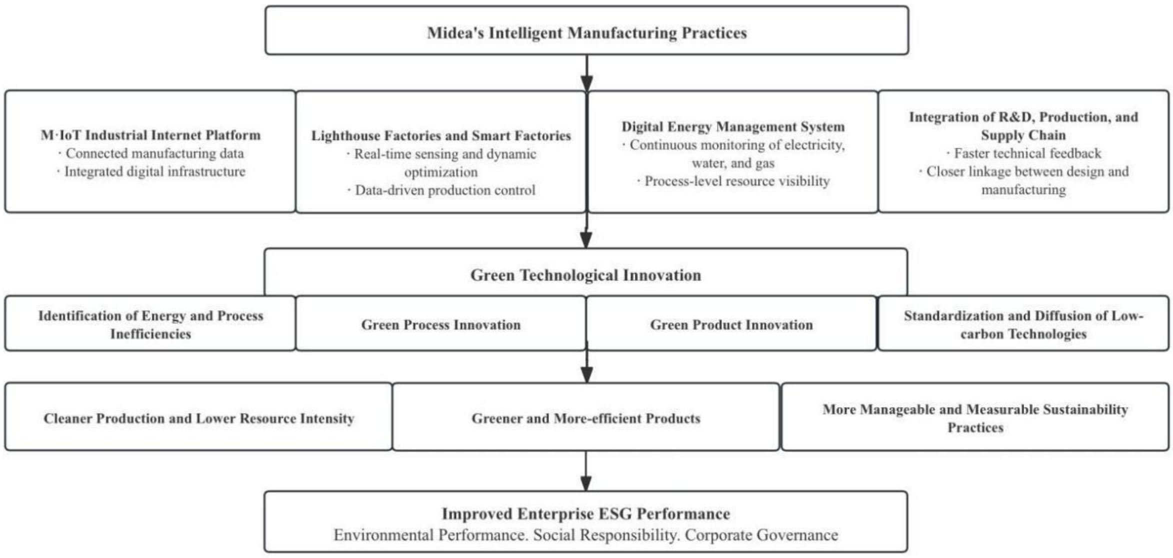
From the perspective of mechanism transmission, the Midea case can be summarized as a relatively clear causal chain. Intelligent manufacturing first creates an interconnected production environment through M·IoT, smart factories, and digital resource-management systems. That environment makes process inefficiencies, abnormal energy use, and material losses more visible. Once those inefficiencies become observable, they can be translated into concrete targets for process redesign, equipment optimization, and low-carbon product development. As these technical improvements are standardized and diffused, green technological innovation moves from individual projects to enterprise-wide capability. The ESG effect appears at this stage: environmental performance improves through cleaner production and lower energy intensity; the social dimension improves through greener and more efficient products that better match consumer demand for sustainable consumption; and governance improves because innovation activities become more measurable, manageable, and aligned with long-term sustainability objectives. In this sense, green technological innovation functions as a substantive transmission channel through which intelligent manufacturing is converted into ESG performance.

The broader significance of the case lies in showing that green innovation can emerge from the internal logic of intelligent manufacturing rather than from external symbolic pressure alone. In many enterprises, green innovation is treated as a parallel agenda, often separated from the core production system and therefore difficult to scale. Midea's practice suggests a different organizational pattern. Smart factories, industrial internet connectivity, and digital energy systems bring technical upgrading into the center of manufacturing operations. As a result, green innovation becomes more continuous because it is fed by real-time data, more targeted because it is directed at identifiable operational problems, and more scalable because digital systems facilitate replication across production units. These are precisely the characteristics that allow green technological innovation to support sustained ESG improvement rather than one-off environmental achievements.

Seen in this light, Midea's relatively strong external sustainability recognition is better understood as the outcome of an internally grounded capability structure than as an isolated reputational result. The company's green factories, lighthouse factories, and sustainability related recognitions are consistent with the proposition that when intelligent manufacturing and green technological upgrading are tightly integrated, enterprises become better able to transform production-side digital capability into externally observable ESG performance. The point is therefore not that intelligent manufacturing automatically leads to better ESG outcomes, but that it creates the organizational conditions under which green technological innovation becomes more feasible, more repeatable, and more consequential. That is the specific contribution of the Midea case to the mechanism analysis.

Overall, Midea's practice provides strong qualitative support for the mediating role of green technological innovation. The case shows that intelligent manufacturing can do more than improve efficiency or reduce labor dependence. More fundamentally, it reconstructs the production environment in ways that make low-carbon and energy-saving innovation easier to identify, test, and diffuse. Through industrial internet platforms, lighthouse factories, digital energy-management systems, and closer coupling between R&D and manufacturing execution, Midea has turned green innovation into a practical extension of intelligent manufacturing. This case therefore substantiates the argument that intelligent manufacturing can positively affect enterprise ESG performance through the channel of green technological innovation.

Figure 3.4 Midea Case: Green Technological Innovation Mechanism Linking Intelligent Manufacturing and Enterprise ESG Performance



Source: Developed by the author

Figure 3.4 illustrates how Midea improves enterprise ESG performance through the mediating role of green technological innovation. Specifically, Midea's intelligent manufacturing practices, including the M·IoT industrial internet platform, lighthouse factories, digital energy management, and the integration of R&D, production, and supply-chain operations, create favorable conditions for identifying process inefficiencies, promoting green process innovation, developing greener products, and diffusing low-carbon technologies. These innovation outcomes support cleaner production, improve product energy efficiency, and strengthen sustainability management, thereby contributing to better ESG performance.

In conclusion, the Midea case substantiates the argument that green technological innovation is a key channel through which intelligent manufacturing contributes to stronger ESG performance. The case makes clear that green innovation in this context is not confined to formal R&D expenditure or isolated patent outcomes; rather, it emerges from the continuous interaction between digitalized production, process optimization, and sustainability-oriented problem solving. At the same time, the case also suggests that this mechanism is unlikely to operate uniformly across enterprises. The ESG benefits of green innovation depend on whether intelligent manufacturing is sufficiently embedded in the enterprise's innovation routines, technical capabilities, and resource-allocation processes. The case therefore supports the mediating effect identified in the regression analysis, while also indicating that the strength of this pathway is contingent on the extent to which intelligent transformation is translated into sustained innovation capability rather than one-off technological upgrading

3.8.4 Intelligent Manufacturing and the Alleviation of Financing Constraints: Case Evidence

CATL is a global leader of new energy innovative technologies, committed to providing premier solutions and services for new energy applications worldwide. It provides a particularly valuable empirical context for clarifying how intelligent manufacturing may alleviate financing constraints and thereby improve enterprise ESG performance. In the power battery industry, production expansion, technological iteration, and supply-chain coordination all require sustained capital input. This financing demand is amplified by the industry's strong dependence on R&D, large-scale fixed-asset investment, strict quality control, and increasingly demanding environmental and safety requirements. Under these conditions, financing capacity depends not only on an enterprise's external capital access in a narrow sense, but also on whether it can demonstrate stable production capability, credible technological competence, and reliable long-term growth prospects. CATL is especially instructive in this regard because its intelligent manufacturing transformation has been accompanied by a visible strengthening of production efficiency, quality stability, operational cash generation, and capital-market recognition. To supplement the quantitative evidence on the mediating role of financing constraints, this section examines CATL as the focal case for this mechanism. CATL was selected not only because of its leading position in the new-energy manufacturing sector, but more importantly because its intelligent-manufacturing practices provide a particularly strong setting in which to observe the financial consequences of organizational upgrading. Through intelligent factories, highly automated production lines, digitalized quality control, and data-based process management, CATL has strengthened operational stability, quality consistency, and production credibility. These features are analytically important because they help explain how intelligent manufacturing may improve enterprise ESG performance indirectly by reinforcing internal financial resilience, reducing external uncertainty, and improving access to capital.

CATL's intelligent manufacturing system is built around industrial internet connectivity, AI-assisted inspection, machine learning, predictive algorithms, digital platforms, and 5G-enabled factory operations. The company has developed what it describes as an efficient intelligent factory and established five data platforms covering R&D, testing, manufacturing, operation, and after-sales activities. Its manufacturing network also includes real-time quality monitoring across more than 7,000 control points and a life-cycle quality-tracking system in which data are retained for more than 20 years. These arrangements indicate that intelligent manufacturing in CATL's case is not limited to equipment automation. Rather, it reorganizes production around continuous data generation, integrated quality control, and full-process traceability. Such a production system strengthens the observability and predictability of operations, both of which are highly relevant to financing conditions in a capital-intensive manufacturing enterprise.

The financing significance of these practices is first reflected in the enhancement of internal financing capacity. Enterprises facing financing constraints do not rely exclusively on external borrowing or equity financing; they also depend on the extent to which operating activities can generate sufficient internal funds to support expansion, innovation, and sustainability related investment. CATL's intelligent manufacturing system appears to improve this internal funding capacity by reducing production frictions, increasing process efficiency, and strengthening quality consistency. Its Sichuan facility was designated a National Intelligent Manufacturing Bench-marking Enterprise, reflecting the maturity of the production system developed there. CATL also reports that digital-twin applications increased productivity in product development and manufacturing by 25 percent, while AI-based detection and intelligent energy regulation at the Liyang plant increased inspection efficiency by 60 percent, improved workshop energy efficiency by 16 percent, reduced unit energy consumption by 47 percent, and shortened debugging cycles by 40 percent. Improvements of this kind are financially consequential because they reduce operational waste, improve asset utilization, and strengthen cash-flow generation. For an enterprise with large and continuous capital needs, stronger internally generated funds directly mitigate financing pressure.

CATL's recent financial position is consistent with this interpretation. In the first half of 2024, the company reported operating cash flow of RMB 44.7 billion and a closing cash balance of RMB 255 billion. During the same period, S&P Global Ratings and Moody's upgraded CATL to A ratings and maintained a stable outlook. These developments are analytically important because they show that intelligent manufacturing contributes to financing conditions through more than one pathway. On the one hand, efficiency gains and production reliability strengthen internal liquidity. On the other hand, improved operating performance and a more disciplined production system enhance the enterprise's external credit standing. In this sense, intelligent manufacturing alleviates financing constraints both by increasing internal financial resilience and by improving the enterprise's profile in external capital markets.

The external financing channel is closely tied to the reduction of information uncertainty. Creditors and investors evaluate manufacturing enterprises under conditions of incomplete information, particularly when capacity expansion is rapid and technological complexity is high. A digitally controlled and traceable production system reduces this uncertainty because it makes quality outcomes, production discipline, and operational reliability easier to assess. CATL’s intelligent manufacturing architecture incorporates AI inspection, predictive algorithms, real-time monitoring, and full life-cycle quality tracking. These arrangements improve not only production performance itself, but also the transparency and credibility of that performance. For external financiers, an enterprise whose production processes are digitally integrated and quality-traceable presents lower informational opacity than one whose manufacturing system remains fragmented and manually controlled. Lower informational opacity, in turn, supports more favorable financing conditions.

CATL’s offshore bond issuance illustrates this point. In 2020, the company issued USD 1.5 billion in dual-tranche offshore bonds. The offering attracted an order book exceeding USD 13.5 billion, equivalent to roughly nine times over-subscription, and the final pricing spreads were substantially narrower than the initial guidance. The issuance widened CATL’s financing channels and optimized its financing structure, particularly for overseas expansion. Although bond demand is shaped by multiple factors, the strength of investor reception is consistent with the view that CATL’s manufacturing capability and operating credibility had become legible to capital-market participants. Intelligent manufacturing matters here because it underpins precisely those attributes, production stability, quality control, scalability, and execution reliability, that reduce perceived financing risk.

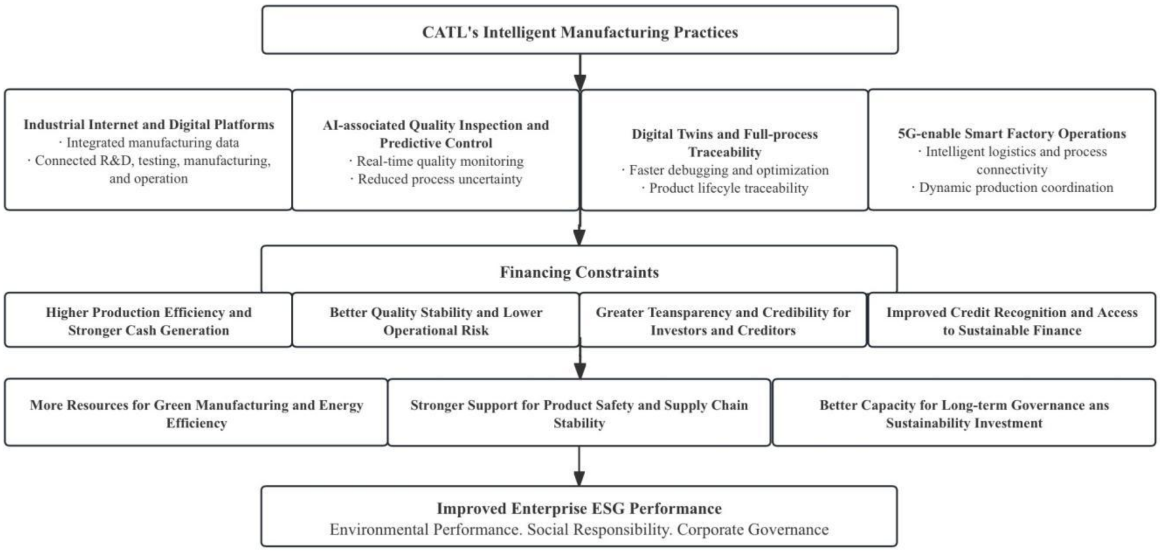
The connection between intelligent manufacturing and financing capacity is also reinforced by CATL’s move toward sustainable finance. In its climate-related disclosure, the company explicitly notes that capital markets tend to favor more environmentally friendly and resilient enterprises by providing them with lower-cost financing or lower financing thresholds for eligible projects. The same disclosure indicates that CATL is planning to establish a green or sustainable finance framework, clarify the objectives and use of funds after financing, and monitor financing opportunities in bond and credit products associated with environmentally friendly and sustainable transformation. This is important because financing-constraint alleviation in CATL’s case is not merely an incidental consequence of growth. It is increasingly embedded in a financing strategy that connects intelligent manufacturing, green transformation, and capital-market access. Intelligent manufacturing gives this strategy operational credibility: digitalized production, traceable quality systems, and resource-efficiency improvements make the enterprise’s sustainable-finance orientation more persuasive to lenders and investors.

CATL's emphasis on intelligent and low-carbon production capacity further strengthens this relationship. The company's intelligent manufacturing profile highlights membership in the World Economic Forum's Global Lighthouse Network, and its broader production strategy has increasingly incorporated green intelligent manufacturing bases and low-carbon industrial development. In the Chinese policy context, such production assets carry financial significance beyond immediate profitability. They align the enterprise with policy priorities in advanced manufacturing, energy transition, and industrial upgrading, all of which affect the supply of credit, bond financing, and strategic investor support. Financing constraints are therefore eased not only because intelligent manufacturing improves efficiency, but also because it enhances the strategic legitimacy and future-oriented asset quality of the enterprise.

Within this case, the link from intelligent manufacturing to ESG performance through financing conditions is relatively clear. Intelligent manufacturing strengthens production efficiency, traceability, and energy performance through AI inspection, industrial internet systems, predictive control, and digital platforms. These improvements contribute to stronger cash generation, better credit recognition, and lower information asymmetry in capital markets. Once financing constraints are relaxed, the enterprise is better positioned to sustain the long-cycle investments required for ESG related transformation. In environmental terms, easier access to capital supports continued investment in intelligent energy regulation, zero-carbon factories, and cleaner production systems. In social terms, stronger financing capacity supports supply-chain stability, product quality assurance, and sustained technological investment in safer and more reliable battery products. In governance terms, a combination of traceable production, disciplined capital access, and stronger investor confidence improves internal control, strategic consistency, and accountability to stakeholders. Financing-constraint alleviation therefore operates as a substantive transmission channel rather than as a purely financial by-product.

CATL's practice thus provides strong qualitative support for the proposition that intelligent manufacturing can improve enterprise ESG performance through the alleviation of financing constraints. What emerges from the case is not a simple claim that digital production automatically attracts capital. The more defensible conclusion is that intelligent manufacturing enhances operational efficiency, stabilizes production quality, strengthens internal cash-flow generation, improves external assessability, and supports alignment with sustainable-finance preferences. These changes jointly reduce the intensity of financing frictions and enlarge the enterprise's capacity to undertake sustained ESG oriented investment. In this way, CATL's experience is consistent with the mechanism identified in the quantitative analysis: intelligent manufacturing contributes to better ESG performance in part because it relaxes the financing constraints under which enterprises make long-term sustainability decisions.

Figure 3.5 CATL Case: Financing Constraints Mechanism Linking Intelligent Manufacturing and Enterprise ESG Performance



Source: Developed by the author

Figure 3.5 illustrates how CATL improves enterprise ESG performance through the alleviation of financing constraints. Specifically, CATL's intelligent manufacturing practices, including industrial internet platforms, AI-assisted quality inspection, digital twins, and 5G-enabled smart factory operations, improve production efficiency, strengthen quality stability, reduce operational risk, and enhance the transparency and credibility of the firm for investors and creditors. These changes help alleviate financing constraints by improving internal cash generation, credit recognition, and access to sustainable finance. As financing conditions improve, CATL is better positioned to support green manufacturing investment, product and supply-chain stability, and long-term sustainability governance, thereby contributing to better ESG performance.

In summary, the CATL case suggests that the financing-constraints channel is more complex than a standard positive mediation mechanism. On the one hand, intelligent manufacturing can strengthen operational credibility, improve quality consistency, and enhance the enterprise's long-term financing conditions by increasing resilience, transparency, and production reliability. On the other hand, intelligent transformation itself is capital-intensive, technologically demanding, and often accompanied by substantial upfront expenditure, long payback periods, and heightened adjustment pressure. As a result, the shortto medium-term financial burden created by intelligent upgrading may partially offset its ESG enhancing effect, even when the longer-term direction remains favorable. In this sense, the case is broadly consistent with the regression results indicating a suppressing mediation effect of financing constraints: intelligent manufacturing does not simply relax financial pressure in a linear manner, but may simultaneously generate new capital demands and transitional frictions during the course of ESG improvement. The case therefore refines the quantitative finding by showing that the financing channel operates through a tension between capability enhancement and transformation cost, rather than through an unambiguously positive easing effect.

3.8.5 Intelligent Manufacturing and Synergistic Governance: Case Evidence

Seres provides a particularly suitable case for clarifying the synergistic-governance mechanism through which intelligent manufacturing affects enterprise ESG performance. In the new-energy vehicle industry, ESG outcomes depend not only on the efficiency of a single plant or the environmental performance of a single production link, but also on whether production, logistics, quality control, supplier management, carbon management, and board-level oversight can be coordinated within a coherent governance structure. This requirement makes synergistic governance especially important. Seres is analytically valuable in this respect because its intelligent manufacturing transformation has been accompanied by the construction of a super factory, an IoT based manufacturing platform, supply-chain coordination arrangements, and a more formal ESG governance framework. These practices make it possible to observe how intelligent manufacturing can strengthen cross-functional and cross-organizational coordination, and how such coordination can be translated into better ESG performance. Seres' super factory has been described by the company as operating under a "four-in-one" intelligent manufacturing architecture with over 3,000 robots working collaboratively, 100% automation in key processes, and 100% quality-monitoring traceability, all supported by an advanced IoT platform.

To complement the quantitative evidence on the mediating role of synergistic governance, this section examines Seres as the focal case for this mechanism. Seres was selected because its intelligent-manufacturing transformation is especially suitable for illustrating how digitalized production systems can be linked to broader forms of organizational and inter-organizational coordination. As a technology-driven new-energy vehicle manufacturer, Seres has combined smart-factory construction, digital carbon-management systems, and supply-chain collaboration mechanisms in ways that extend intelligent manufacturing beyond the shop floor. This makes the case particularly appropriate for examining whether intelligent manufacturing improves enterprise ESG performance by strengthening coordinated governance across production, energy management, and upstream-downstream relationships.

The governance relevance of these practices lies in the fact that intelligent manufacturing changes the organizational basis of coordination. In conventional manufacturing systems, production, procurement, warehousing, logistics, quality inspection, and environmental management are often handled through separate chains of command and fragmented information systems. Under such conditions, governance tends to be segmented: departments optimize their own tasks, but the enterprise as a whole faces coordination frictions, delayed information transfer, and weak alignment between operational execution and sustainability objectives. Seres' intelligent manufacturing model moves in a different direction. Its super factory integrates intelligent terminals, IoT connectivity, and digitalized process control into one production architecture. Once key production links are automated and fully traceable, information is no longer confined to isolated workshops or departmental records. It becomes shared operational infrastructure. This change is fundamental for synergistic governance because coordination improves only when different actors work on the basis of synchronized and visible information.

The practical significance of this arrangement is most evident in production-side coordination. Seres' super factory is organized around collaborative robotics, real-time process control, and full-process quality traceability. These features do more than raise efficiency. They enable production, quality assurance, equipment management, and logistics functions to operate through the same data environment. In governance terms, this reduces the institutional separation between execution and supervision. Quality control no longer depends solely on ex post inspection, and production coordination no longer depends solely on hierarchical transmission. Instead, data generated during production become directly usable for monitoring, correction, and organizational response. A manufacturing system of this kind is more conducive to synergistic governance because it allows multiple operational units to coordinate around common process indicators and shared accountability.

This integrative effect extends beyond the factory floor to the supply chain. Public disclosures from Seres emphasize that the company uses its intelligent manufacturing platform to build a supply ecosystem oriented toward collaborative innovation and agile delivery. In the context of new-energy vehicle production, this is especially important because supply-chain governance is closely tied to ESG outcomes. Product safety, responsible sourcing, compliance, delivery stability, and environmental performance all depend on whether suppliers are effectively integrated into the enterprise's broader governance framework. Seres' approach suggests that intelligent manufacturing is being used not merely to optimize internal production, but to connect upstream and downstream actors through a more coordinated production and delivery system. In such a setting, synergistic governance is expressed as the capacity to align suppliers, manufacturing operations, and delivery systems around common standards of responsiveness and control.

The same governance logic can be observed in Seres' treatment of suppliers and business partners. The company's ESG reporting states that it has issued rules such as the *Management Measures for Integrity Cooperation with Business Partners* and *the Self-discipline Integrity Management Measures*, adopts zero tolerance toward suppliers' violations of business ethics, and requires suppliers to sign integrity commitments upon entry. It also reports internal systems for supplier information security management and third-party information security governance. These arrangements are significant because they show that the governance system around intelligent manufacturing is not confined to production efficiency. It extends to formal standards that regulate partner behavior, information handling, and ethical compliance. Synergistic governance in this case is therefore not a vague concept of cooperation. It is a structured combination of digital coordination and institutionalized partner management

Environmental governance in Seres is also organized in a coordinated manner that is closely linked to its intelligent manufacturing system. The company has emphasized the integration of green concepts across the full product life-cycle, including design, production, logistics, and recycling, and has publicized a digital carbon-management platform alongside low-carbon operational initiatives such as a zero-carbon smart logistics port project using autonomous electric heavy trucks powered by green electricity. These practices are analytically important because they indicate that environmental performance is not being treated as a downstream reporting issue separated from production. Instead, carbon management, logistics, manufacturing, and product design are being linked through digital tools and coordinated operational arrangements. This is a concrete manifestation of synergistic governance: environmental objectives are incorporated into a governance structure that spans multiple business functions rather than left to a single environmental department.

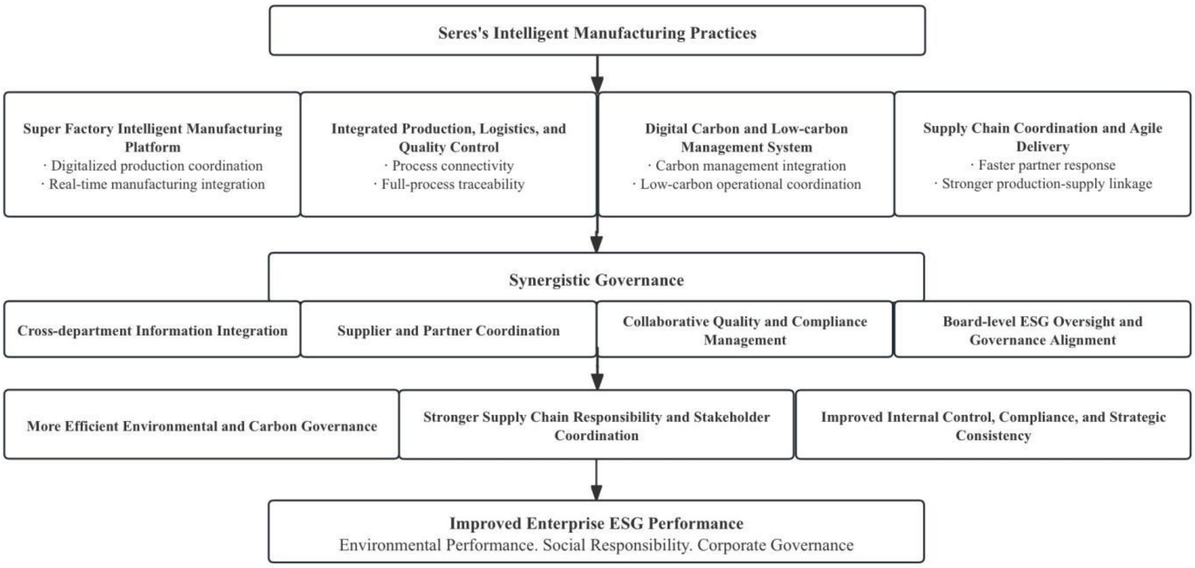
Board-level arrangements reinforce this pattern. Seres reported the establishment of an ESG Committee in 2023 in order to further standardize corporate governance and strengthen risk management and internal control. The significance of this development lies in the upward integration of ESG issues into the formal governance system of the company. Intelligent manufacturing generates more timely and traceable information at the production and supply-chain levels, but the ESG consequences of that information depend on whether it enters the enterprise's decision-making structure. The establishment of a dedicated ESG Committee indicates that Seres has created an organizational channel through which operational and sustainability-related issues can be reviewed within a formal governance framework. Synergistic governance therefore operates both horizontally and vertically: horizontally, through coordination across departments and supply-chain actors; vertically, through alignment between intelligent operations and board-level oversight.

Within this case, the mechanism linking intelligent manufacturing to ESG performance through synergistic governance is relatively clear. Intelligent manufacturing first creates a digitally integrated production environment through the super factory, IoT platforms, automation, and traceability systems. That environment improves cross-department information sharing and reduces coordination frictions among production, logistics, quality control, and environmental management functions. These improvements are then extended outward through supplier integrity commitments, information-security requirements, and supply-chain coordination arrangements, and upward through the ESG Committee and stronger internal-control structures. As a result, governance becomes more collaborative, more standardized, and more responsive across the enterprise's internal and external networks. ESG performance improves because environmental management is better coordinated across life-cycle stages, supply-chain responsibility is more effectively embedded in partner governance, and corporate governance becomes more structured and accountable.

The ESG implications of this governance pattern are substantial. On the environmental dimension, coordinated carbon management across design, production, logistics, and recycling strengthens the enterprise's capacity to implement low-carbon transformation in a substantive rather than symbolic way. On the social dimension, stronger supplier governance, quality traceability, and agile delivery coordination improve stakeholder protection by reducing product and compliance risks across the value chain. On the governance dimension, the combination of intelligent manufacturing, partner-management rules, and formal ESG oversight enhances internal control, ethical discipline, and accountability. These outcomes are consistent with the proposition that synergistic governance is a meaningful mediating channel rather than a residual by-product of digitalization.

Seres' practice therefore provides qualitative support for the view that intelligent manufacturing can improve enterprise ESG performance through synergistic governance. The case does not suggest that digital production alone is sufficient. The more convincing conclusion is that intelligent manufacturing becomes ESG relevant when it is embedded in a governance structure that connects production systems, supply-chain relationships, carbon-management arrangements, and board-level oversight. In Seres' case, the super factory, IoT-based manufacturing platform, supplier governance rules, life-cycle environmental management, and ESG Committee jointly indicate such a structure. This makes the company a useful case for showing how intelligent manufacturing can be translated into stronger synergistic governance and, through that channel, into better enterprise ESG performance.

Figure 3.6 Seres Case: Synergistic Governance Mechanism Linking Intelligent Manufacturing and Enterprise ESG Performance



Source: Developed by the author

Figure 3.6 illustrates how Seres improves enterprise ESG performance through the mediating role of synergistic governance. Specifically, Seres's intelligent manufacturing practices, including its super factory platform, integrated production and quality-control system, digital carbon management, and supply-chain coordination arrangements, strengthen cross-department information integration, partner coordination, collaborative quality and compliance management, and board-level ESG governance alignment. These changes improve environmental and carbon governance, reinforce supply-chain responsibility and stakeholder coordination, and strengthen internal control and strategic consistency, thereby contributing to better ESG performance.

Overall, the Seres' practice therefore provides qualitative support for the view that intelligent manufacturing improves ESG performance through synergistic governance. The case also shows how internal governance conflicts generated by technological transformation can be managed in practice. In Seres, smart-factory construction and IoT based production systems create shared operational data, while traceability systems clarify responsibility across production, logistics, quality control, and environmental management. Supplier governance rules extend accountability beyond internal departments, and the ESG Committee provides a formal channel for reviewing operational issues from a sustainability perspective. Through these arrangements, potential tensions among production efficiency, transformation cost, compliance requirements, and ESG objectives are not left to informal negotiation among departments. They are embedded in data-based coordination, responsibility clarification, cross-functional review, and board-level oversight. This suggests that intelligent manufacturing becomes ESG relevant when technological upgrading is accompanied by governance arrangements capable of aligning operational decisions with sustainability objectives.

3.8.6 Comparison Between Quantitative and Qualitative Findings

The preceding quantitative and qualitative analyses provide two complementary forms of evidence regarding the relationship between intelligent manufacturing and enterprise ESG performance. To facilitate a more systematic comparison, Table 3.29 summarizes the correspondence between the main quantitative findings and the qualitative case evidence across the baseline effect, the four mediating mechanisms, and the heterogeneity analysis. The table is not intended merely as a descriptive summary. Rather, it serves to clarify the extent to which the statistical results obtained from the large-sample econometric analysis are supported, refined, and substantively interpreted by the case-based evidence developed in the qualitative inquiry.

Table 3.29 Comparison of Quantitative Results and Qualitative Findings

Hypothesis	Mechanism	Quantitative Evidence	Qualitative Case Evidence	Consistency Assessment
H1	Overall effect of Intelligent Manufacturing	Baseline fixed-effects regressions show that intelligent manufacturing has a significantly positive effect on enterprise ESG performance	Case firms exhibit simultaneous improvements in intelligent manufacturing practices and ESG outcomes across environmental, social, and governance dimensions	Highly consistent
H2	Information Transparency	Mediation analysis indicates that information transparency significantly mediates the relationship between intelligent manufacturing and ESG performance	**Haier Smart Home** COSMOPlat enables real-time data collection and traceability, reducing information asymmetry and improving ESG disclosure credibility	Strongly consistent
H3	Green Technological Innovation	Results show a significant mediating role of green innovation between	**Midea Group** smart energy systems, green design, and life-cycle	Strongly consistent

		intelligent manufacturing and ESG performance	management promote green innovation and circular economy practices	
H4	Financing Constraints	Intelligent manufacturing significantly alleviates financing constraints, which in turn improves ESG performance	**CATL** intelligent production enhances operational stability and cash flow, improves access to green finance, and supports sustained ESG investment	Strongly consistent
H5	Synergistic Governance	Synergistic governance exhibits a significant mediating effect in the intelligent manufacturing ESG relationship	**Seres** digital carbon management and smart factory systems strengthen cross-departmental and supply-chain coordination	Strongly consistent
H6-H8	Heterogeneity Effects	Significant differences observed across regions, technological attributes, and listing boards	Case firms are predominantly located in developed regions, technologically advanced, and listed on major exchanges	Contextually consistent

Source: Developed by the author

Table 3.29 provides a systematic comparison between the quantitative results and qualitative case findings. The evidence demonstrates a high degree of consistency between the econometric estimations and the firm-level case narratives. While quantitative analysis identifies statistically significant effects and mediation mechanisms, qualitative evidence illustrates how intelligent manufacturing practices operate in real organizational settings. This convergence strengthens the robustness of the findings and supports the validity of the proposed theoretical framework.

Overall, the comparison reveals a high degree of consistency between the quantitative and qualitative findings. The econometric analysis shows that intelligent manufacturing exerts a significantly positive effect on enterprise ESG performance, and that this effect is transmitted through four mediating mechanisms: information transparency, green technological innovation, the alleviation of financing constraints, and synergistic governance. The qualitative case studies are broadly aligned with this conclusion. In each case, intelligent manufacturing is associated not merely with the adoption of advanced equipment or production automation, but with deeper organizational changes involving digital integration, process traceability, operational coordination, governance restructuring, and sustainability-oriented capability building. The case evidence therefore supports the central proposition advanced in the quantitative analysis, namely that intelligent manufacturing improves enterprise ESG performance through multiple organizational and institutional pathways rather than through a simple and direct productivity effect alone.

The consistency of the two types of evidence is especially clear with respect to the baseline effect of intelligent manufacturing on enterprise ESG performance. The quantitative results indicate that intelligent manufacturing has a statistically significant and robust positive impact on ESG performance. This finding is mirrored in the four case enterprises, all of which exhibit a broad coexistence of intelligent manufacturing transformation and relatively strong ESG oriented practices. The qualitative evidence suggests that this coexistence is not incidental. In the cases of Haier, Midea, CATL, and Seres, intelligent manufacturing has been embedded in a wider system of operational upgrading, digital management, and organizational coordination, thereby creating conditions under which environmental performance, social responsibility, and governance quality can improve simultaneously. The qualitative findings thus reinforce the interpretation that intelligent manufacturing should be understood as a multidimensional organizational transformation with sustainability implications.

The information transparency mechanism presents a particularly strong case of convergence between the quantitative and qualitative evidence. The mediation analysis indicates that information transparency plays a significant role in explaining how intelligent manufacturing improves enterprise ESG performance. This statistical result is closely aligned with the Haier case. Haier's intelligent manufacturing transformation, centered on COSMOPlat and related digital systems, has made production, quality, energy, and supply-chain information more visible, traceable, and internally shareable. The significance of this case lies in showing that information transparency is not limited to outward disclosure at the reporting stage. Rather, it is generated at the stage of production and management through real-time data capture, process traceability, and integrated information systems. Such practices reduce internal and external information asymmetry, strengthen the credibility of disclosure, and improve the enterprise's ability to manage environmental, social, and governance issues on the basis of verifiable information. The qualitative evidence therefore provides a concrete organizational explanation for why information transparency emerges as a significant mediating channel in the quantitative analysis.

A similar degree of consistency is observed in the green technological innovation mechanism. The quantitative findings indicate that green technological innovation significantly mediates the relationship between intelligent manufacturing and enterprise ESG performance. The Midea case gives substantive meaning to this result by showing how intelligent manufacturing reshapes the enterprise's innovation environment. Midea's industrial internet platform, lighthouse factories, and digital energy-management systems have reduced the separation between production operations and technological upgrading. In this setting, intelligent manufacturing makes process inefficiencies and resource-consumption problems more visible, facilitates the testing and diffusion of low-carbon technologies, and supports the scaling of greener products and processes. The case evidence therefore clarifies that green technological innovation is not an isolated R&D outcome, but is deeply embedded in the digital and operational architecture of intelligent manufacturing. This strengthens the interpretation of the quantitative mediation result by showing how intelligent manufacturing turns green innovation into a continuous and implementable organizational capability.

The financing constraints mechanism also displays strong consistency across the two forms of evidence. The quantitative analysis suggests that intelligent manufacturing improves ESG performance by alleviating financing constraints. The CATL case supports this conclusion by illustrating how intelligent manufacturing can improve financing conditions through both internal and external channels. Internally, intelligent factories, AI-assisted inspection, digital twins, and predictive control enhance operational efficiency, quality stability, and cash generation capacity, thereby strengthening internal financial resilience. Externally, the same intelligent manufacturing capabilities improve production credibility, product traceability, and operational transparency, thereby reducing the uncertainty faced by investors and creditors. This contributes to stronger credit recognition, expanded financing channels, and lower financing frictions. The case evidence is therefore consistent with the econometric result while also refining it. It indicates that financing constraint alleviation should not be understood solely in terms of access to external capital, but also in terms of the stronger internal financial capacity and external assessability generated by intelligent manufacturing.

The synergistic governance mechanism shows a comparable pattern of mutual reinforcement. The quantitative analysis identifies synergistic governance as a significant mediating variable in the intelligent manufacturing ESG relationship. The Seres case provides process-based support for this mechanism. Seres' super factory platform, integrated production and logistics system, digital carbon-management tools, supplier coordination arrangements, and board-level ESG oversight collectively illustrate how intelligent manufacturing can strengthen governance coordination across departments, processes, supply-chain partners, and organizational levels. The case demonstrates that synergistic governance is not an abstract managerial trait, but a concrete organizational outcome of digital integration.

When production, logistics, quality control, environmental management, and partner governance are linked through intelligent systems, governance becomes more collaborative, more standardized, and more responsive. This strengthens the environmental, social, and governance dimensions of enterprise performance simultaneously. The qualitative findings therefore help explain why synergistic governance emerges as a meaningful positive transmission mechanism in the quantitative analysis.

Although the quantitative and qualitative findings are broadly consistent, the two approaches contribute differently to the explanatory structure of the dissertation. The quantitative analysis is based on a large sample of Chinese A-share listed firms and is able to identify systematic relationships, estimate effect sizes, and test the statistical significance of the proposed hypotheses. Its strength lies in demonstrating that the intelligent manufacturing - ESG relationship is general rather than anecdotal. The qualitative analysis, by contrast, operates at the level of organizational process and practical implementation. Its strength lies in revealing how the mechanisms identified in the econometric analysis are activated in concrete firm settings. In this sense, the quantitative findings establish whether intelligent manufacturing matters for ESG performance, whereas the qualitative findings clarify how and why this effect is produced in practice. The two forms of evidence are therefore complementary rather than substituent.

The comparison also deepens the causal interpretation of the empirical results. Statistical mediation analysis can demonstrate that certain variables function as significant transmission channels, but it cannot fully reveal the internal organizational processes through which those channels operate. The case evidence addresses this limitation by identifying the actual managerial and operational practices associated with each mechanism. Haier shows how intelligent manufacturing enhances the transparency of information through real-time data generation and traceable production systems. Midea shows how digital manufacturing environments facilitate the identification, application, and diffusion of green technologies. CATL shows how intelligent manufacturing can improve both internal cash-flow strength and external financing credibility. Seres shows how intelligent manufacturing supports governance coordination across production, supply-chain, environmental, and board-level systems. These qualitative details increase the plausibility of the mechanism interpretation and strengthen the overall explanatory power of the dissertation.

The heterogeneity analysis presents a somewhat different pattern. The quantitative results indicate that the ESG effects of intelligent manufacturing vary across regional development levels, technological attributes, and capital market segmentation. The qualitative evidence is broadly compatible with this conclusion, but its role is more contextual than confirmatory. The four selected case firms are predominantly located in relatively developed regions, operate in technologically advanced industries, and are positioned within major capital-market or policy-supported environments. These characteristics are consistent with the quantitative finding that the ESG effects of intelligent manufacturing tend to be more pronounced under more favorable institutional and market conditions. At the same time, the qualitative evidence does not independently test heterogeneity in a comparative statistical sense. Its contribution lies in illustrating the kinds of organizational and institutional contexts in which intelligent manufacturing is most likely to generate visible ESG effects. For this reason, the consistency of the qualitative and quantitative findings in the heterogeneity dimension is better understood as contextual support rather than direct mechanism validation.

From a methodological standpoint, the comparison confirms the value of combining quantitative and qualitative approaches in the study of intelligent manufacturing and ESG performance. The relationship under investigation is multidimensional, involving technological transformation, organizational adaptation, governance restructuring, and institutional embeddedness. A single research strategy would be insufficient to capture all of these dimensions. Quantitative analysis provides rigor, generalizability, and statistical identification, but necessarily abstracts from firm-level process variation. Qualitative case analysis captures that variation, but cannot independently establish broader population-level patterns. The integration of the two approaches therefore enhances the robustness and credibility of the conclusions. The convergence of findings across methods reduces the likelihood that the main conclusions are driven by model-specific assumptions or isolated firm narratives, and instead suggests that the positive ESG effects of intelligent manufacturing reflect a substantively meaningful and empirically grounded relationship.

In summary, the comparison between quantitative and qualitative findings strongly supports the central argument of this dissertation. Intelligent manufacturing exerts a positive influence on enterprise ESG performance, and this influence is realized through multiple mediating mechanisms rather than through a single direct pathway. Information transparency, green technological innovation, the alleviation of financing constraints, and synergistic governance all function as meaningful transmission channels linking intelligent manufacturing to sustainable corporate outcomes. The quantitative analysis establishes the general pattern and statistical significance of these relationships, while the qualitative case evidence reveals the organizational practices and processual logic through which they are realized. Taken together, the two forms of evidence provide a coherent and mutually reinforcing basis for concluding that intelligent manufacturing constitutes an important driver of enterprise ESG performance in the Chinese context.

CONCLUSION AND RECOMMENDATION

Conclusion

This study examines the role of intelligent manufacturing in shaping enterprise ESG performance within the broader context of China's industrial transformation. Rather than approaching intelligent manufacturing only as a technical shift in production, the analysis treats it as a deeper reorganization of enterprise operations, information systems, innovation processes, and governance arrangements. Against this backdrop, the dissertation investigates how such transformation is associated with enterprises' environmental, social, and governance outcomes and what this relationship implies for sustainable corporate development.

A primary conclusion emerging from the analysis is that intelligent manufacturing is positively associated with stronger ESG performance at the enterprise level. Enterprises advancing further in intelligent transformation tend to display better overall sustainability performance. This relationship suggests that the significance of intelligent manufacturing is not confined to efficiency enhancement or production upgrading. More fundamentally, it appears to influence how enterprises organize sustainability-related activities, respond to external expectations, and incorporate longer-term governance considerations into business operations. In this sense, intelligent manufacturing is better understood as part of the broader architecture of high-quality corporate development rather than as an isolated technological initiative.

The second conclusion is that the link between intelligent manufacturing and ESG performance is sustained by an interconnected set of internal processes. The effect does not arise in a simple or automatic way once intelligent technologies are introduced. Instead, it depends on whether technological transformation is able to improve the conditions under which enterprises disclose information, generate green innovation, secure financial support, and coordinate internal as well as external governance relationships. The overall picture that emerges is therefore one of organizational restructuring: intelligent manufacturing matters for ESG not simply because it upgrades equipment, but because it alters the underlying systems through which enterprises pursue sustainability-related objectives. This also clarifies the efficiency-to-ESG logic of the dissertation. Intelligent manufacturing improves enterprise ESG performance not simply by increasing output efficiency, but by making production processes more visible, controllable, and coordinated. These operational changes create the conditions under which enterprises can reduce resource waste, improve green innovation, strengthen disclosure credibility, obtain more stable resource support, and implement ESG-related objectives more effectively.

Improved information conditions constitute one important pathway through which intelligent manufacturing strengthens enterprise ESG performance. As production systems become more digitalized, interconnected, and traceable, enterprises are better positioned to produce timely, reliable, and verifiable information concerning operations, resource use, and governance practices. Such improvements reduce opacity, strengthen accountability, and support more credible ESG related communication with stakeholders. The implication is that the sustainability relevance of intelligent manufacturing lies partly in its capacity to reshape the informational environment of the enterprise.

Green technological innovation represents another key avenue through which intelligent transformation is translated into ESG improvement. Intelligent manufacturing facilitates a production setting in which data feedback, process optimization, and system integration can be connected more directly to cleaner production, energy efficiency, waste reduction, and environmentally oriented redesign. The significance of this finding lies in showing that the value of intelligent transformation for ESG is not merely additive. Rather, intelligent systems may create the organizational conditions under which green innovation becomes more continuous, more scalable, and more deeply embedded in the everyday logic of production and management.

Financial conditions also play a meaningful role in shaping the ESG implications of intelligent manufacturing. Intelligent transformation often requires substantial upfront investment, longer adjustment cycles, and sustained resource commitment. Under such circumstances, the capacity of enterprises to maintain stable financing conditions becomes highly relevant to whether sustainability-oriented investment can be continued and absorbed. The findings suggest that intelligent manufacturing can improve the feasibility of ESG related action when it strengthens operational credibility, internal efficiency, and external confidence, thereby easing financial pressure over time. This indicates that the sustainability consequences of technological transformation are tied not only to production capability, but also to the financial viability of organizational change.

In addition, governance coordination forms an important part of the overall explanatory picture. Intelligent manufacturing appears to matter for ESG when it supports stronger integration across departments, functions, and stakeholders, allowing enterprises to align production, environmental management, compliance, and strategic decision-making more effectively. Where intelligent systems are linked to broader coordination structures, enterprises are better able to reduce fragmentation, improve responsiveness, and implement sustainability-related goals in a more coherent manner. This suggests that the governance value of intelligent manufacturing lies not only in process automation or data visibility, but also in its capacity to support more coherent and adaptive organizational coordination.

Another important conclusion is that the sustainability implications of intelligent manufacturing are unevenly distributed. The effect is not equally strong across all enterprises and contexts. Instead, it varies according to differences in regional environment, technological capability, and market setting. Intelligent manufacturing should therefore not be regarded as a universally effective route to ESG enhancement under all circumstances. Its practical significance depends on whether enterprises possess the absorptive capacity, institutional support, and developmental conditions needed to turn technological transformation into tangible sustainability outcomes. The broader implication is that intelligent manufacturing is embedded in context, and its impact is shaped by the environment in which enterprise transformation unfolds.

A further conclusion concerns the value of combining quantitative and qualitative evidence in the final interpretation of the study. The statistical analysis establishes the overall pattern and internal structure of the relationship, while the case evidence reveals how that relationship is enacted through concrete organizational practices. The two forms of evidence therefore serve distinct but complementary purposes: one identifies regularities across enterprises, and the other clarifies the practical pathways through which those regularities are produced. Their convergence strengthens confidence in the study's central claims because the relationship is shown to be not only empirically observable, but also organizationally intelligible. The force of the dissertation's conclusions thus rests on more than statistical association alone; it also rests on evidence that the same relationship can be traced in the actual processes of enterprise transformation.

Viewed from a broader theoretical angle, the dissertation indicates that intelligent manufacturing is most meaningfully interpreted as a reconfiguration of enterprise capability. Its relevance to ESG lies in the fact that it changes how enterprises process information, organize innovation, mobilize resources, and coordinate action in response to stakeholder and institutional pressures. This helps explain why the relationship identified in the study cannot be reduced to a narrow productivity story. The deeper issue is not simply that enterprises become more efficient, but that they acquire a different organizational basis for sustaining environmental responsibility, social responsiveness, and governance effectiveness over time.

The dissertation also recognizes that this transformation may involve adjustment costs. Intelligent manufacturing may improve efficiency, but its contribution to ESG performance depends on whether enterprises can properly manage employment adjustment, skill transformation, data responsibility, and internal coordination during technological upgrading. The significance of this dissertation lies not only in showing that intelligent manufacturing improves enterprise ESG performance, but in generating a more explicit theoretical understanding of how and under what conditions this effect takes shape. Four new insights emerge from the findings.

First, the dissertation shows that intelligent manufacturing should be understood not merely as a production technology or efficiency-enhancing tool, but as a sustainability-relevant organizational capability. Its importance for ESG does not lie only in technical upgrading itself, but in its ability to reconfigure how enterprises process information, organize innovation, mobilize resources, and coordinate action in response to environmental, social, and governance demands. This finding helps move the discussion of intelligent manufacturing beyond a narrow productivity-centered framework and places it more clearly within the broader literature on sustainable corporate development.

Second, the mechanism analysis further explains how intelligent manufacturing is translated into enterprise ESG improvement. The four mediating mechanisms identified in this dissertation do not play identical roles. Information transparency and green technological innovation constitute the more direct explanatory channels. The former improves data traceability, process visibility, disclosure quality, and external monitoring, thereby reducing information asymmetry and strengthening stakeholder trust. The latter links intelligent manufacturing more directly with sustainability outcomes by promoting cleaner production, energy-saving processes, and green technological outputs. Financing constraints and synergistic governance play more enabling roles. The alleviation of financing constraints determines whether firms have sufficient financial resources to sustain ESG related investment, while synergistic governance determines whether digital technologies can be converted into coordinated ESG execution across departments, processes, and stakeholder interfaces. Therefore, the four mechanisms should be understood as an integrated transmission structure rather than as isolated channels: intelligent manufacturing improves information conditions and green innovation capacity, while financial-resource support and governance coordination determine whether these advantages can be transformed into sustained ESG performance.

The dimension-specific results also show that the impact of intelligent manufacturing is not completely uniform across the environmental, social, and governance dimensions. The supplementary regressions indicate that the coefficient of intelligent manufacturing is largest for the environmental dimension, followed by the social dimension, while the governance dimension shows a smaller but still positive effect. This suggests that intelligent manufacturing contributes most immediately to environmental improvement, mainly through cleaner production, resource efficiency, emission reduction, and green technological innovation. Its positive effect on the social dimension reflects improvements in operational quality, employee and stakeholder responsiveness, and supply-chain responsibility. The governance effect is relatively more gradual, because governance improvement depends not only on digital tools, but also on organizational adjustment, internal control, responsibility allocation, and board-level oversight. Overall, intelligent manufacturing improves ESG performance through a multidimensional process, with its strongest and most immediate contribution reflected in the environmental dimension.

Third, the dissertation shows that the ESG value of intelligent manufacturing is context-contingent. The heterogeneity results indicate that intelligent manufacturing does not generate equally strong ESG effects across all enterprises. Its influence depends on whether firms possess the institutional support, absorptive capacity, and developmental conditions required to convert intelligent upgrading into sustained sustainability outcomes. This finding adds an important boundary-condition perspective to existing research by showing that the ESG implications of intelligent manufacturing are conditional rather than universal.

Fourth, the dissertation contributes a more integrated explanatory framework by combining econometric evidence with qualitative case interpretation. The quantitative analysis identifies the general pattern, transmission mechanisms, and heterogeneous effects of the relationship, while the qualitative evidence clarifies how these mechanisms are enacted in concrete organizational settings. The value of this combination is not merely methodological. It also strengthens the theoretical interpretation of the study by linking general statistical regularities with observable organizational processes. As a result, the dissertation contributes not only evidence that intelligent manufacturing matters for enterprise ESG performance, but also a more grounded explanation of how such effects emerge in practice.

Finally, the findings should also be interpreted within a China-oriented ESG evaluation framework. By using the Huazheng ESG rating, this dissertation captures enterprise ESG performance in a way that reflects the regulatory environment, disclosure practices, and stakeholder expectations of Chinese listed companies. The robustness check using the Wind

ESG rating further indicates that the positive effect of intelligent manufacturing is not confined to one specific domestic ESG rating measure. However, the dissertation does not assume that domestic and international ESG rating systems are identical or fully substitutable. A systematic comparison between Chinese and international ESG rating systems remains an important direction for future research.

Taken together, these insights suggest that intelligent manufacturing should be theorized as a context-dependent organizational transformation whose ESG significance lies in its capacity to reshape the internal conditions under which sustainability performance is produced. In this sense, the dissertation contributes new knowledge not simply by identifying a positive association between intelligent manufacturing and enterprise ESG performance, but by explaining why this relationship exists, through what organizational logic it operates, and under what conditions it becomes more pronounced.

Several limitations should nevertheless be recognized. The measurement of both intelligent manufacturing and ESG performance remains constrained by data availability and by the multidimensional nature of the two constructs. In addition, although the analysis employs multiple empirical strategies to enhance reliability, further work may still refine causal identification through more sharply exogenous settings or more fine-grained research designs. The present study is also based on Chinese A-share listed firms, with financial and real estate firms excluded from the final empirical sample, which means that caution is needed when extending the conclusions to non-listed firms, smaller enterprises, or other institutional environments. Future research may therefore improve measurement, broaden the range of samples, and investigate additional organizational processes that may connect intelligent transformation with sustainability outcomes. These limitations do not alter the main conclusions of the dissertation, but they do indicate that the relationship between intelligent manufacturing and enterprise ESG performance remains a fertile area for continued theoretical and empirical inquiry.

Research Contributions

This dissertation makes four principal academic contributions to the existing literature.

First, it extends the analytical boundary of intelligent manufacturing research by empirically linking intelligent manufacturing to enterprise ESG performance. Existing studies have focused mainly on productivity, innovation output, operational efficiency, and firm value. By contrast, this dissertation brings intelligent manufacturing into closer dialogue with research on sustainable corporate development and shows that its relevance also extends to enterprise environmental, social, and governance outcomes. In this way, the study broadens the scope of intelligent manufacturing research and provides a more integrated basis for connecting technological upgrading with enterprise sustainability.

Second, it contributes a more differentiated mechanism-based explanation of how intelligent manufacturing affects enterprise ESG performance. Rather than treating the relationship as direct or uniformly positive, the dissertation shows that the ESG consequences of intelligent transformation are transmitted through multiple organizational channels, including information transparency, green technological innovation, financing constraints, and synergistic governance. In doing so, it advances the literature from a simple effect-identification approach toward a more structured explanation of the internal organizational logic through which technological transformation is translated into sustainability outcomes.

Third, it contributes a clearer boundary-condition perspective by demonstrating that the ESG effects of intelligent manufacturing are context-dependent. The dissertation shows that the relationship varies systematically across regional environments, technological attributes, and capital-market settings. This finding enriches existing scholarship by indicating that intelligent manufacturing should not be interpreted as a universally effective route to ESG enhancement, but as a conditional governance mechanism whose effectiveness depends on both institutional environment and firm-level capability.

Fourth, it contributes an integrated mixed-methods explanation of the intelligent manufacturing - ESG relationship. By combining quantitative evidence with qualitative case interpretation, the dissertation moves beyond identifying average statistical effects and provides a more grounded account of how the identified mechanisms operate in real organizational settings. This strengthens the explanatory depth of the study and offers a more complete framework for understanding how intelligent transformation becomes translated into enterprise ESG improvement.

Finally, the dissertation also offers a context-sensitive measurement implication for ESG-related empirical research. By adopting the Huazheng ESG rating as the main dependent variable and using the Wind ESG rating as an alternative measure in the robustness test, the dissertation improves the reliability of ESG performance measurement. This treatment helps ensure that the empirical conclusion is derived from a rating framework consistent with the sample characteristics, disclosure environment, and institutional setting of Chinese A-share listed companies.

Taken together, these contributions clarify the analytical scope, internal mechanisms, and boundary conditions of the relationship between intelligent manufacturing and enterprise ESG performance, and provide a more coherent explanation of how intelligent transformation becomes associated with sustainable corporate development.

Recommendations

The findings of this dissertation have direct implications for governments, enterprises, and capital-market actors. Overall, the results suggest that intelligent manufacturing policy and enterprise transformation strategy should be more closely coordinated with ESG related institutional support, innovation policy, governance improvement, and financial arrangements. On this basis, the following recommendations are proposed.

(1) Recommendations for Governments and Regulatory Authorities

First, governments should re-frame intelligent manufacturing policy within a broader agenda of sustainable industrial transformation. The results of this dissertation indicate that intelligent manufacturing should not be treated only as an instrument for improving productivity, automation, or industrial competitiveness. Its significance extends to environmental, social, and governance performance, which means that industrial policy and sustainability policy should be designed in a more coordinated manner. In practical terms, policy frameworks for intelligent manufacturing should be linked more explicitly with green transition strategies, ESG related disclosure requirements, and broader reforms aimed at improving the quality of corporate governance. Such coordination is necessary if intelligent transformation is to generate not only technical upgrading, but also broader sustainability gains.

Second, regulatory authorities should strengthen the institutional foundations that enable intelligent manufacturing to enhance ESG performance through greater information transparency. Since the dissertation identifies information transparency as a key enabling mechanism, policymakers should focus on improving enterprise data governance, digital reporting infrastructure, industrial information interoperability, and ESG disclosure standardization. More reliable and comparable disclosure systems would reduce information asymmetry, improve external monitoring, and make the sustainability effects of intelligent manufacturing more visible and more credible. In this sense, digital infrastructure policy and ESG disclosure regulation should not be treated as separate domains, but as mutually reinforcing components of the same transformation process.

Third, governments should treat green technological innovation as a strategic complement to intelligent manufacturing rather than as a parallel policy objective. The findings indicate that one of the main ways in which intelligent manufacturing improves ESG performance is by strengthening green innovation capability. This implies that public support for intelligent transformation should be designed in ways that encourage cleaner production, energy optimization, low-carbon process upgrading, waste reduction, and green product innovation. Policy tools such as targeted tax incentives, collaborative research platforms, industrial demonstration projects, and sustainability-oriented innovation subsidies can help ensure that intelligent upgrading is directed toward both economic and environmental value creation.

Fourth, policy intervention should be differentiated rather than uniform. The empirical results show that the ESG effects of intelligent manufacturing are stronger in some contexts than in others, which suggests that enterprises do not begin the transformation process from the same institutional, technological, or sectoral production conditions. For high-tech and innovation-intensive enterprises, policy support may focus on linking intelligent manufacturing demonstration projects with green innovation incentives, ESG information disclosure, digital carbon management, and sustainable finance instruments. These enterprises are generally better positioned to transform intelligent manufacturing into green innovation, process transparency, and governance modernization. For non-high-tech and more traditional production-oriented enterprises, the policy priority should be to strengthen the basic conditions under which intelligent manufacturing can generate ESG benefits. These include digital infrastructure, process standardization, employee training, environmental monitoring systems, and access to transformation finance. A differentiated policy approach is therefore preferable to a uniform strategy, because it allows intelligent manufacturing to serve as a more inclusive pathway to sustainability across enterprises with different technological foundations and sectoral production conditions. This differentiated policy logic is also important for SMEs. Since SMEs often face weaker digital infrastructure, stronger financing constraints, less formalized governance systems, and lower ESG disclosure capacity, the policy implications drawn from listed firms should not be mechanically applied to them. Instead, governments should support SMEs through modular intelligent equipment, shared digital platforms in industrial parks, cloud-based manufacturing services, technical training, and simplified ESG reporting guidance. At the same time, leading enterprises in industrial chains can be encouraged to transfer technical standards, data interfaces, green process requirements, and ESG management experience to upstream and downstream SMEs. Such a chain-based and platform-based approach would allow SMEs to participate in intelligent and sustainable transformation under more realistic resource constraints.

Fifth, governments should strengthen the policy linkage between intelligent manufacturing and sustainable finance. Because the dissertation shows that financing constraints can weaken the positive ESG effects of intelligent transformation, industrial policy should be coordinated with financial policy so as to reduce the transitional burden borne by enterprises. Governments can play an important role by encouraging green credit programs, sustainability-linked lending, technology-upgrading funds, and public-private financing instruments that support projects combining intelligent manufacturing with environmental improvement and governance modernization. Without such financial support, some enterprises may adopt intelligent technologies in form, but fail to realize their deeper sustainability benefits in substance. For this reason, policy support should also encourage milestone-based and phased financing arrangements so that enterprises can expand intelligent transformation gradually while maintaining alignment between investment affordability and ESG objective.

(2) Recommendations for Enterprises

For enterprises, the central implication of this dissertation is that intelligent manufacturing should be managed not merely as a technical investment, but as a staged strategic allocation problem involving technology, governance, and capital. Enterprises should not assume that automation, digital equipment, or intelligent systems will automatically improve ESG performance. Instead, they should incorporate intelligent manufacturing into long-term strategic planning and link it to a limited number of clearly prioritized ESG objectives, such as energy efficiency, emissions control, process traceability, compliance quality, or supply-chain coordination. In practical terms, the immediate managerial task is not to maximize the speed or scale of transformation, but to sequence investment so that limited resources are first directed to those business processes in which operational upgrading and ESG improvement can be achieved simultaneously. Enterprises should therefore establish an internal conflict-management mechanism throughout intelligent transformation. Before project approval, ESG related objectives should be incorporated into budget design, implementation plans, and post-evaluation criteria, so that transformation is assessed not only by output efficiency and cost reduction, but also by energy use, emission reduction, disclosure quality, employee adjustment, supplier responsibility, and governance accountability. During implementation, decision rights and responsibility boundaries should be clarified among production, technology, finance, compliance, internal control, human resources, and supply-chain functions. Major transformation projects should be reviewed by cross-functional committees or the ESG committee, with board-level oversight where necessary. Performance evaluation should also include ESG related indicators to reduce the conflict between short-term managerial incentives and long-term sustainability objectives. In this way, internal conflicts caused by technological transformation can be transformed into a structured governance process, allowing intelligent manufacturing to support substantive ESG improvement rather than remaining a narrow technical project.

Enterprises should also establish a responsible transition mechanism when implementing intelligent manufacturing. Before expanding automation and intelligent systems on a large scale, enterprises should assess the possible effects on job structure, employee skills, workplace safety, and internal responsibility boundaries. For positions affected by technological substitution, enterprises should provide retraining, job redesign, internal transfer opportunities, and transparent communication channels. These measures can reduce employment uncertainty and help employees adapt to new production and management systems. In addition, the evaluation of intelligent manufacturing projects should not focus only on productivity, cost reduction, and output growth. Enterprises should also include social and governance indicators, such as employee training coverage, labor adjustment arrangements, workplace safety, data compliance, and cross-functional coordination. This can help enterprises transform intelligent manufacturing from a narrow efficiency tool into a more responsible pathway for ESG improvement. Intelligent transformation should not be evaluated only by cost reduction, productivity improvement, or technical upgrading. Before implementation, enterprises should assess its possible effects on employment structure, employee skills, workplace safety, data governance, and internal responsibility boundaries. During implementation, automation should be combined with employee retraining, job redesign, internal transfer opportunities, and transparent communication. For positions that may be replaced by intelligent equipment, priority should be given to reskilling and redeployment rather than simple workforce reduction.

At the governance level, major intelligent transformation projects should be reviewed through cross-functional procedures involving production, technology, finance, human resources, ESG, compliance, and internal control departments. Such review should consider not only investment returns, but also employee adjustment, environmental compliance, data responsibility, supplier impact, and long-term ESG value. Performance evaluation should also include indicators related to employee training, labor stability, information transparency, compliance quality, and stakeholder responsibility. Through these arrangements, the potential negative effects of technology introduction can be reduced, and intelligent manufacturing can be transformed from a narrow technical project into a responsible and sustainable organizational change.

A second recommendation is that enterprises should improve the quality of internal and external information systems during intelligent transformation. Since information transparency is found to be one of the most important channels through which intelligent manufacturing enhances ESG performance, enterprises should invest in digital traceability systems, real-time process monitoring, integrated data platforms, and more reliable ESG related reporting practices. The purpose of such investment is not merely to disclose more information, but to improve the consistency, verifiability, and managerial usefulness of information generated across production, environmental management, compliance, and governance functions. Enterprises that can translate intelligent transformation into better information quality are more likely to convert technological capability into sustained ESG improvement.

Third, enterprises should embed green technological innovation into the implementation of intelligent manufacturing. The study suggests that intelligent transformation yields stronger ESG gains when it stimulates green process innovation, cleaner production methods, more efficient resource use, and environmentally oriented product development. For this reason, enterprises should avoid implementing intelligent manufacturing solely in the pursuit of efficiency gains or labor substitution. Instead, they should design transformation strategies that connect manufacturing intelligence with R&D, environmental management, and long-term sustainability planning. The more closely intelligent systems are linked to green innovation capacity, the more likely it is that intelligent manufacturing will produce substantive rather than symbolic ESG improvement.

Fourth, enterprises should adopt a phased implementation mechanism to balance the high cost of intelligent transformation with ESG requirements. Rather than attempting enterprise-wide upgrading at once, enterprises should begin with pilot projects in processes where operational benefits and ESG relevance overlap most clearly, such as energy-intensive production links, high-emission processes, quality-traceability systems, or supply-chain coordination nodes. Before each phase is expanded, the enterprise should evaluate both economic and ESG indicators, including investment burden, efficiency gains, energy use, waste reduction, information quality, and compliance performance. Only after pilot-stage benefits are verified and financing capacity is secured should transformation be extended to additional units. Such sequencing reduces the risk of over-investment, prevents ESG from becoming a symbolic add-on, and helps enterprises convert intelligent upgrading into measurable and sustainable organizational gains.

Fifth, enterprises should establish a financing and communication arrangement that matches the long-cycle nature of intelligent transformation. In practical terms, this means combining internal capital budgeting with external instruments such as green credit, sustainability-linked loans, technology-upgrading funds, or other transition-finance tools, while disclosing transformation objectives, implementation milestones, and ESG outcomes to investors and lenders in a timely manner. A dedicated cross-functional coordination mechanism involving production, finance, strategy, ESG, compliance, and supply-chain management should also be put in place to review investment priorities, monitor implementation risk, and adjust financing pace when cost pressure becomes excessive. This helps enterprises avoid fragmented capital commitments, reduce financing frictions, and maintain a workable balance between transformation cost and ESG performance requirements.

(3) Recommendations for Financial Institutions and Capital Markets

The findings of this dissertation also have important implications for financial institutions and capital markets. Since intelligent manufacturing is shown to have positive implications for enterprise ESG performance, financial actors should broaden the criteria through which they evaluate enterprises undergoing technological transformation. Rather than relying solely on short-term profitability or traditional accounting ratios, lenders and investors should incorporate intelligent-manufacturing capability into assessments of enterprises' long-term sustainability potential, governance quality, and adaptive capacity. Such an approach would improve the identification of enterprises whose technological upgrading is likely to generate broader strategic and ESG benefits.

Second, financial institutions should design instruments that reduce the capital pressure associated with intelligent transformation. Because financing constraints are found to weaken the ESG enhancing effects of intelligent manufacturing, access to appropriately structured finance is likely to influence whether enterprises can complete intelligent transformation in a substantive and sustainable manner. For listed firms, green credit, sustainability-linked loans, innovation-oriented industrial finance, and transition-finance mechanisms may support projects that combine intelligent upgrading with environmental improvement, disclosure enhancement, and governance reform. For SMEs, however, financing support should be more staged and accessible, because many SMEs lack standardized ESG ratings, sufficient collateral, and stable access to long-term capital. Financial institutions may therefore develop smaller-scale, milestone-based, and supply-chain-oriented financing instruments, supported by credit guarantees, policy-oriented loans, and platform-based data verification. This would help reduce information asymmetry and allow SMEs to participate in intelligent and sustainable transformation without bearing excessive upfront financial pressure.

Third, capital-market institutions should encourage more integrated evaluation standards linking intelligent manufacturing with ESG performance. Rating agencies, analysts, institutional investors, and stock exchanges should place greater emphasis on whether enterprises' intelligent-manufacturing investments are accompanied by improvements in information quality, innovation orientation, environmental performance, and governance capacity. A more integrated evaluative framework would help distinguish substantive intelligent transformation from superficial technology adoption, and would also encourage enterprises to pursue intelligent upgrading in ways that are more closely tied to long-term sustainability outcomes.

(4) Extended Recommendations for Mongolia and Other Late-Industrializing Economies

Although the empirical basis of this dissertation is China's manufacturing sector, the findings also offer carefully bounded implications for Mongolia and other late-industrializing economies. These implications should not be interpreted as a direct transfer of results from one country to another; rather, they should be understood as analytical lessons that may inform policy and managerial choices in contexts where industrial modernization, institutional development, and sustainability governance are evolving simultaneously.

For Mongolia, one major implication is that intelligent manufacturing should be embedded within a long-term strategy of industrial modernization rather than treated as a narrow program of equipment replacement or production automation. The dissertation suggests that intelligent manufacturing can generate broader sustainability gains only when it is linked to information infrastructure, innovation capability, financing support, and governance improvement. In a country where industrial capacity and institutional support systems may be unevenly distributed, this means that policy emphasis should be placed not merely on acquiring advanced technologies, but on building the complementary conditions that allow such technologies to generate wider developmental effects.

A second implication concerns digital and informational infrastructure. Since this dissertation identifies information transparency as a crucial mechanism through which intelligent manufacturing improves ESG performance, Mongolia may benefit from strengthening enterprise data governance, digital reporting systems, and the institutional basis for more standardized non-financial disclosure. These steps would not only support industrial modernization, but also improve enterprise accountability, investor confidence, and the governance quality of enterprises participating in industrial transformation.

A third implication is that intelligent-manufacturing promotion in Mongolia should be closely linked to green innovation and resource-efficiency objectives. Rather than treating digital upgrading and environmental sustainability as separate agendas, policymakers and enterprises may seek to connect intelligent technologies with cleaner production, energy management, emissions control, and environmentally oriented process innovation. This is especially relevant for late-industrializing economies, where the opportunity exists to avoid some of the lock-in effects associated with older, more resource-intensive industrial pathways.

A fourth implication concerns financing. The dissertation shows that financing constraints can weaken the ESG benefits of intelligent transformation, and this lesson may be particularly salient in economies where long-term industrial finance remains limited. Mongolia may therefore consider developing targeted financing arrangements for intelligent and green industrial upgrading, including preferential credit, development-finance support, pilot investment funds, and financing mechanisms tied to sustainability-related performance improvement. Such instruments may reduce the burden on enterprises and increase the likelihood that intelligent transformation will be implemented in a substantively effective manner.

Finally, Mongolian enterprises should approach intelligent manufacturing as a managerial and organizational transition rather than as a simple procurement decision. Technology acquisition without corresponding investment in skills, coordination systems, governance practices, and environmental management is unlikely to produce meaningful ESG gains. A gradual and context-sensitive implementation strategy, supported by pilot projects, sector-specific experimentation, and capability-building initiatives, would therefore be more appropriate than an undifferentiated push for rapid technological adoption.

(5) Toward A Coordinated Sustainability Ecosystem

The recommendations of this dissertation point to the need for a more coordinated sustainability ecosystem in which intelligent manufacturing, ESG governance, green innovation, and sustainable finance reinforce one another. The central lesson of the study is that intelligent transformation becomes most valuable not when it is pursued in isolation, but when it is embedded within a broader institutional and organizational framework that supports transparency, innovation, financial viability, and governance adaptation.

For this reason, fragmented interventions are unlikely to generate the full sustainability potential of intelligent manufacturing. What is required instead is a coordinated approach in which governments provide supportive institutions and differentiated policy design, enterprises pursue intelligent transformation as an integrated strategic change process, financial institutions supply appropriately structured long-term support, and capital markets reward substantive rather than symbolic upgrading. Under such conditions, intelligent manufacturing can move beyond its conventional role as a source of production efficiency and become a more stable driver of enterprise ESG improvement and sustainable industrial development.

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APPENDIX

Appendix Note

The appendix presents a set of supplementary dimension-specific regressions for the environmental, social, and governance components of enterprise ESG performance. These appendix tables are intended to complement, rather than duplicate or replace, the main-text analysis based on the overall ESG index. Appendix 1 reports the baseline regressions for the three ESG sub-dimensions, while Appendix 2-13 provide supplementary mediation tests for information transparency, green technological innovation, financing constraints, and synergistic governance across the environmental, social, and governance dimensions separately. Taken together, these appendix materials offer additional detail on the sub-dimensional structure of the empirical results and clarify how the strength of individual mechanisms may vary across E, S, and G outcomes.

Appendix 1 Baseline Regression Results for the Effects of Intelligent Manufacturing on the E, S, and G Dimensions of ESG Performance

	(1) E	(2) S	(3) G
IM	2.0124*	1.8003*	0.8032**
	(1.80)	(1.742)	(2.36)
SIZE	0.0124***	0.0023***	-0.0058
	(45.78)	(3.92)	(-0.45)
LEV	1.9966	-0.0485***	-0.9527***
	(1.01)	(-10.92)	(-18.04)
ROA	-0.0519	-0.0434***	-0.0519
	(-0.74)	(-5.60)	(-0.74)
Top1	0.0170	0.0460***	0.0170
	(0.18)	(12.32)	(0.18)
Age	-0.1335	0.0045***	-0.1335
	(-1.06)	(10.75)	(-1.06)
SOE	-0.0058	0.0450***	0.0043
	(-0.45)	(4.04)	(0.13)
Year	Yes	Yes	Yes
Firm	Yes	Yes	Yes
_cons	-0.1379***	0.0473***	0.1832***
	(-10.26)	(123.88)	(5.52)
N	30347	30347	30347
adj. R^2	0.122	0.409	0.489

Source: Developed by the author

Notes: The dependent variables are the environmental (E), social (S), and governance (G) dimensions of enterprise ESG performance. IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 2 Mediating Effect of Information Transparency on the Environmental Dimension of ESG Performance

	(1) Epoint	(2) TRANS	(3) Epoint
IM	8.5683***	0.0164*	5.6517***
	(6.73)	(2.23)	(5.60)
SIZE	1.2997***	0.0328***	1.4901***
	(11.40)	(11.45)	(12.85)
LEV	-3.8732***	0.0527***	-3.0036***
	(-8.87)	(4.80)	(-6.78)
ROA	-1.1581*	0.0214	-1.5243***
	(-1.96)	(1.49)	(-2.58)
Top1	-1.1803	-0.0876***	-1.5566**
	(-1.53)	(-4.51)	(-2.02)
Age	-0.8332	0.3678***	1.4652
	(-0.82)	(13.38)	(1.34)
SOE	-0.3798	0.0066	-0.4170
	(-1.41)	(1.00)	(-1.56)
TRANS			0.5436*
			(1.89)
_cons	7.5267***	-1.7063***	5.9089***
	(9.94)	(-16.93)	(6.43)
N	28468	28468	28468
adj. R^2	0.468	0.447	0.490

Source: Developed by the author

Notes: The dependent variables are the environmental dimension of enterprise ESG performance (Epoint) in columns (1) and (3), and information transparency (TRANS) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 3 Mediating Effect of Green Technological Innovation on the Environmental Dimension of ESG Performance

	(1) Epoint	(2) GTI	(3) Epoint
IM	8.5683^{***}	0.1970^{**}	7.5937^{***}
	(6.73)	(1.97)	(5.74)
SIZE	1.2997^{***}	0.0472^{***}	1.2909^{***}
	(11.40)	(11.65)	(11.30)
LEV	-3.8732^{***}	-0.0227	-3.8696^{***}
	(-8.87)	(-1.46)	(-8.86)
ROA	-1.1581^{*}	-0.0191	-1.1537^{*}
	(-1.96)	(-0.93)	(-1.95)
Top1	-1.1803	0.1672^{***}	-1.2115
	(-1.53)	(6.01)	(-1.57)
Age	-0.8332	-0.5381^{***}	-0.7184
	(-0.82)	(-14.58)	(-0.71)
SOE	-0.3798	-0.0128	-0.3776
	(-1.41)	(-1.36)	(-1.41)
GTI			0.2022^{*}
			(1.67)
_cons	7.5267^{***}	0.6218^{***}	7.3665^{***}
	(9.94)	(4.56)	(9.89)
N	28468	28468	28468
adj. R^2	0.468	0.832	0.468

Source: Developed by the author

Notes: The dependent variables are the environmental dimension of enterprise ESG performance (Epoint) in columns (1) and (3), and green technological innovation (GTI) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 4 Mediating Effect of Financing Constraints on the Environmental Dimension of ESG Performance

	(1) Epoint	(2) KZ	(3) Epoint
IM	8.5683***	-5.1499***	8.1176***
	(6.73)	(-8.79)	(6.11)
SIZE	1.2638***	-0.4836***	1.2242***
	(12.30)	(-20.55)	(11.84)
LEV	-3.4396***	6.5613***	-2.8761***
	(-8.51)	(71.05)	(-6.56)
ROA	-1.1062*	-5.3600***	-1.5985***
	(-1.93)	(-41.82)	(-2.70)
Top1	-0.2068	-0.3698**	-0.2371
	(-0.30)	(-2.30)	(-0.34)
Age	-0.8048	3.0215***	-0.5440
	(-0.90)	(14.54)	(-0.61)
SOE	-0.2369	-0.0565	-0.2428
	(-0.94)	(-0.99)	(-0.96)
KZ			-0.0856***
			(-3.29)
_cons	37.5745***	0.3450	37.5575***
	(11.18)	(0.44)	(11.18)
N	28468	28468	28468
adj. R^2	0.468	0.711	0.472

Source: Developed by the author

Notes: The dependent variables are the environmental dimension of enterprise ESG performance (Epoint) in columns (1) and (3), and financing constraints (KZ) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 5 Mediating Effect of Synergistic Governance on the Environmental Dimension of ESG Performance

	(1) Epoint	(2) DEM	(3) Epoint
IM	8.5683***	0.0542*	8.5247***
	(6.73)	(1.80)	(6.73)
SIZE	1.2997***	0.0025**	1.3011***
	(11.40)	(2.02)	(11.41)
LEV	-3.8732***	-0.0006	-3.8728***
	(-8.87)	(-0.13)	(-8.87)
ROA	-1.1581*	0.3949***	-0.8409
	(-1.96)	(63.35)	(-1.32)
Top1	-1.1803	0.0063	-1.1723
	(-1.53)	(0.75)	(-1.52)
Age	-0.8332	0.0029	-0.8277
	(-0.82)	(0.26)	(-0.82)
SOE	-0.3798	-0.0047*	-0.3837
	(-1.41)	(-1.66)	(-1.43)
DEM			0.8041*
			(1.89)
_cons	7.5267***	-0.0780*	7.4672***
	(9.94)	(-1.89)	(9.93)
N	28468	28468	28468
adj. R^2	0.468	0.214	0.468

Source: Developed by the author

Notes: The dependent variables are the environmental dimension of enterprise ESG performance (Epoint) in columns (1) and (3), and synergistic governance (DEM) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 6 Mediating Effect of Information Transparency on the Social Dimension of ESG Performance

	(1) Spoint	(2) TRANS	(3) Spoint
IM	5.0852*	0.0164*	5.0811*
	(1.76)	(1.83)	(1.84)
SIZE	1.4359***	0.0328***	1.4152***
	(10.62)	(11.45)	(10.09)
LEV	-0.3101	0.0527***	-0.1747
	(-0.60)	(4.80)	(-0.33)
ROA	2.4533***	0.0214	2.5743***
	(3.50)	(1.49)	(3.60)
Top1	-0.7942	-0.0876***	-1.2098
	(-0.87)	(-4.51)	(-1.30)
Age	3.0439**	0.3678***	2.1893*
	(2.53)	(13.38)	(1.66)
SOE	0.1845	0.0066	0.1651
	(0.58)	(1.00)	(0.51)
TRANS			0.1396*
			(1.74)
_cons	4.7881***	-1.7063***	7.8335***
	(7.77)	(-16.93)	(7.76)
N	28468	28468	28468
adj. R^2	0.429	0.447	0.434

Source: Developed by the author

Notes: The dependent variables are the social dimension of enterprise ESG performance (Spoint) in columns (1) and (3), and information transparency (TRANS) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 7 Mediating Effect of Green Technological Innovation on the Social Dimension of ESG Performance

	(1) Spoint	(2) GTI	(3) Spoint
IM	5.0852*	0.1970**	4.8997*
	(1.76)	(1.97)	(1.86)
SIZE	1.4359***	0.0472***	1.3948***
	(10.62)	(11.65)	(10.30)
LEV	-0.3101	-0.0227	-0.2931
	(-0.60)	(-1.46)	(-0.57)
ROA	2.4533***	-0.0191	2.4738***
	(3.50)	(-0.93)	(3.53)
Top1	-0.7942	0.1672***	-0.9396
	(-0.87)	(6.01)	(-1.03)
Age	3.0439**	-0.5381***	3.5781***
	(2.53)	(-14.58)	(2.96)
SOE	0.1845	-0.0128	0.1946
	(0.58)	(-1.36)	(0.61)
GTI			0.9415***
			(4.59)
_cons	4.7881***	0.6218***	4.0420***
	(7.77)	(4.56)	(7.61)
N	28468	28468	28468
adj. R^2	0.429	0.832	0.429

Source: Developed by the author

Notes: The dependent variables are the social dimension of enterprise ESG performance (Spoint) in columns (1) and (3), and green technological innovation (GTI) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 8 Mediating Effect of Financing Constraints on the Social Dimension of ESG Performance

	(1) Spoint	(2) KZ	(3) Spoint
IM	5.0852*	-5.1499***	5.0635**
	(1.76)	(-8.79)	(2.23)
SIZE	1.4014***	-0.4836***	1.4033***
	(11.34)	(-20.55)	(11.27)
LEV	-0.3945	6.5613***	-0.4217
	(-0.81)	(71.05)	(-0.80)
ROA	2.9878***	-5.3600***	3.0115***
	(4.34)	(-41.82)	(4.23)
Top1	-1.0667	-0.3698**	-1.0652
	(-1.28)	(-2.30)	(-1.28)
Age	3.1430***	3.0215***	3.1304***
	(2.94)	(14.54)	(2.91)
SOE	-0.0979	-0.0565	-0.0976
	(-0.32)	(-0.99)	(-0.32)
KZ			-0.0041**
			(-2.13)
_cons	4.7881***	0.3450	5.2910***
	(7.77)	(0.44)	(8.73)
N	28468	28468	28468
adj. R^2	0.429	0.711	0.438

Source: Developed by the author

Notes: The dependent variables are the social dimension of enterprise ESG performance (Spoint) in columns (1) and (3), and financing constraints (KZ) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 9 Mediating Effect of Synergistic Governance on the Social Dimension of ESG Performance

	(1) Spoint	(2) DEM	(3) Spoint
IM	5.0852*	0.0542*	4.9981*
	(1.76)	(1.80)	(1.86)
SIZE	1.4359***	0.0025**	1.4331***
	(10.62)	(2.02)	(10.60)
LEV	-0.3101	-0.0006	-0.3109
	(-0.60)	(-0.13)	(-0.60)
ROA	2.4533***	0.3949***	1.8190**
	(3.50)	(63.35)	(2.42)
Top1	-0.7942	0.0063	-0.8101
	(-0.87)	(0.75)	(-0.89)
Age	3.0439**	0.0029	3.0330**
	(2.53)	(0.26)	(2.52)
SOE	0.1845	-0.0047*	0.1925
	(0.58)	(-1.66)	(0.60)
DEM			1.6079**
			(2.34)
_cons	4.7881***	-0.0780*	4.9072***
	(7.77)	(-1.89)	(7.80)
N	28468	28468	28468
adj. R^2	0.429	0.214	0.429

Source: Developed by the author

Notes: The dependent variables are the social dimension of enterprise ESG performance (Spoint) in columns (1) and (3), and synergistic governance (DEM) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 10 Mediating Effect of Information Transparency on the Governance Dimension of ESG Performance

	(1) Gpoint	(2) TRANS	(3) Gpoint
IM	1.8539*	0.0164*	1.8508*
	(1.84)	(1.73)	(1.65)
SIZE	1.2832***	0.0328***	1.4723***
	(12.49)	(11.45)	(13.71)
LEV	-10.5648***	0.0527***	-10.3301***
	(-26.86)	(4.80)	(-25.16)
ROA	1.3885***	0.0214	1.1457**
	(2.60)	(1.49)	(2.09)
Top1	0.7176	-0.0876***	0.4356
	(1.03)	(-4.51)	(0.61)
Age	-5.2900***	0.3678***	-3.3287***
	(-5.79)	(13.38)	(-3.30)
SOE	0.7321***	0.0066	0.7594***
	(3.02)	(1.00)	(3.07)
TRANS			0.1819***
			(4.43)
_cons	0.0545***	-1.7063***	9.9064***
	(7.60)	(-6.93)	(6.05)
N	28468	28468	28468
adj. R^2	0.437	0.447	0.435

Source: Developed by the author

Notes: The dependent variables are the governance dimension of enterprise ESG performance (Gpoint) in columns (1) and (3), and information transparency (TRANS) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 11 Mediating Effect of Green Technological Innovation on the Governance Dimension of ESG Performance

	(1) Gpoint	(2) GTI	(3) Gpoint
IM	1.8539^{*}	0.1970^{**}	1.8424^{*}
	(1.84)	(1.97)	(1.74)
SIZE	1.2832^{***}	0.0472^{***}	1.2806^{***}
	(12.49)	(11.65)	(12.44)
LEV	-10.5648^{***}	-0.0227	-10.5638^{***}
	(-26.86)	(-1.46)	(-26.86)
ROA	1.3885^{***}	-0.0191	1.3898^{***}
	(2.60)	(-0.93)	(2.61)
Top1	0.7176	0.1672^{***}	0.7084
	(1.03)	(6.01)	(1.02)
Age	-5.2900^{***}	-0.5381^{***}	-5.2561^{***}
	(-5.79)	(-14.58)	(-5.73)
SOE	0.7321^{***}	-0.0128	0.7328^{***}
	(3.02)	(-1.36)	(3.03)
GTI			0.0597^{*}
			(1.78)
_cons	0.0545^{***}	0.6218^{***}	0.0072^{***}
	(7.60)	(4.56)	(5.57)
N	28468	28468	28468
adj. R^2	0.437	0.832	0.437

Source: Developed by the author

Notes: The dependent variables are the governance dimension of enterprise ESG performance (Gpoint) in columns (1) and (3), and green technological innovation (GTI) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 12 Mediating Effect of Financing Constraints on the Governance Dimension of ESG Performance

	(1) Gpoint	(2) KZ	(3) Gpoint
IM	1.8539*	-5.1499***	1.2930*
	(1.84)	(-8.79)	(1.98)
SIZE	1.1200***	-0.4836***	1.0696***
	(11.94)	(-20.55)	(11.33)
LEV	-10.5648***	6.5613***	-9.4653***
	(-26.86)	(71.05)	(-23.64)
ROA	1.3885***	-5.3600***	1.7121***
	(2.60)	(-41.82)	(3.17)
Top1	0.7176	-0.3698**	1.1913*
	(1.03)	(-2.30)	(1.89)
FirmAge	-5.2900***	3.0215***	-3.8712***
	(-5.79)	(14.54)	(-4.75)
SOE	0.7321***	-0.0565	0.6814***
	(3.02)	(-0.99)	(2.96)
KZ			-0.1089***
			(-4.59)
_cons	0.0545***	0.3450	0.0855***
	(7.60)	(0.44)	(2.85)
N	28468	28468	28468
adj. R^2	0.437	0.711	0.428

Source: Developed by the author

Notes: The dependent variables are the governance dimension of enterprise ESG performance (Gpoint) in columns (1) and (3), and financing constraints (KZ) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix 13 Mediating Effect of Synergistic Governance on the Governance Dimension of ESG Performance

	(1) Gpoint	(2) DEM	(3) Gpoint
IM	1.8539*	0.0542*	1.7812*
	(1.84)	(1.80)	(1.74)
SIZE	1.1200***	0.0025**	1.2809***
	(11.94)	(2.02)	(12.47)
LEV	-10.5648***	-0.0006	-10.5655***
	(-26.86)	(-0.13)	(-26.87)
ROA	1.3885***	0.3949***	0.8593
	(2.60)	(63.35)	(1.50)
Top1	0.7176	0.0063	0.7043
	(1.03)	(0.75)	(1.02)
Age	-5.2900***	0.0029	-5.2991***
	(-5.79)	(0.26)	(-5.80)
SOE	0.7321***	-0.0047*	0.7387***
	(3.02)	(-1.66)	(3.05)
DEM			1.3414**
			(2.57)
_cons	0.0545***	-0.0780*	0.1538***
	(7.60)	(-1.89)	(0.63)
N	28468	28468	28468
adj. R^2	0.437	0.214	0.437

Source: Developed by the author

Notes: The dependent variables are the governance dimension of enterprise ESG performance (Gpoint) in columns (1) and (3), and synergistic governance (DEM) in column (2). IM denotes intelligent manufacturing. t-statistics are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix Summary

To conclude, the dimension-specific supplementary regressions reported in the appendix are broadly consistent with the main-text findings based on the overall ESG measure. At the same time, they indicate that the effects of intelligent manufacturing, as well as the strength and clarity of specific mediating channels, are not entirely uniform across the environmental, social, and governance dimensions. The appendix results therefore provide additional nuance and dimensional refinement to the empirical analysis, while leaving the central conclusions of the dissertation unchanged.

Appendix 14 PSFA-Based Intelligent Manufacturing Index Construction Note

The PSFA-based intelligent manufacturing index used in this dissertation is adopted directly from the CnOpenData database as a firm-year indicator. This appendix is provided to clarify the methodological basis, variable composition, and construction logic of the adopted index for purposes of transparency and replicability.

Appendix 14A. Model Specification

Consistent with the model specification reported in Section 2.2.2, intelligent manufacturing efficiency is estimated as:

$$\mathrm{Ln}(\mathrm{Q}_{i,t}) = \beta_0 + \beta_1 ln(K_{i,t}) + \beta_2 ln(L_{i,t}) + \beta_3[ln(K_{i,t})]^2 + \beta_4[ln(L_{i,t})]^2 + \beta_5 ln(K_{i,t})ln(L_{i,t}) \quad +(v_{i,t} - \mathrm{u}_{i,t}) \quad (2.1)$$

Using the estimated inefficiency term $\mathrm{u}_{i,t}$, the intelligent manufacturing index is calculated as:

$$\mathrm{IM}_{\mathrm{i,t}} = \exp(-\mathrm{u}_{\mathrm{i,t}}) * 100 \quad (2.2)$$

Higher values of $\mathrm{IM}_{\mathrm{i,t}}$ indicates greater intelligent manufacturing efficiency and a higher level of intelligent manufacturing development.

Appendix 14B Definition of Variables in the PSFA-Based Intelligent Manufacturing Index

Symbol	Variable	Definition	Measurement Basis	Data Source
$\mathrm{Q}_{i,t}$	firm output	Annual operating revenue	Realized economic performance of intelligent manufacturing activities	CSMAR Database
$K_{i,t}$	Intelligent manufacturing capital input	Sum of hardware capital and software capital	Hardware: machinery and equipment, electronic devices, computers and auxiliary equipment, communication equipment; Software: software assets under intangible assets	RESSET Database
$L_{i,t}$	Intelligent manufacturing labor input	Production and technical employees	Total number of production and technical employees	WIND Database
$v_{i,t}$	Random noise term	Statistical disturbance	Captures random shocks and measurement noise	Model-estimated
$\mathrm{u}_{i,t}$	Technical inefficiency term	Inefficiency in frontier estimation	Captures deviation from frontier efficiency	Model-estimated
$\mathrm{IM}_{\mathrm{i,t}}$	Intelligent manufacturing index	$\mathrm{IM}_{\mathrm{i,t}} = \exp(-\mathrm{u}_{\mathrm{i,t}}) * 100$	Higher values indicate higher intelligent manufacturing efficiency	CnOpenData Database

Appendix 14C. Construction Logic

The construction logic of the PSFA-based intelligent manufacturing index can be summarized as follows:

(1) collect firm-year data on output ($Q_{i,t}$), intelligent manufacturing capital input ($K_{i,t}$), and intelligent manufacturing labor input ($L_{i,t}$);

(2) Specify the translog stochastic frontier production function;

(3) estimate the inefficiency term ($u_{i,t}$);

(4) transform the inefficiency term into the intelligent manufacturing index ($IM_{i,t} = \exp(-u_{i,t}) * 100$);

(5) interpret higher IM values as indicating a higher level of intelligent manufacturing development.

Appendix 15 Variable Definition and Data Source Supplement

This appendix provides a supplementary overview of the key variables used in the empirical analysis, including their definitions, measurement logic, and principal data sources. It is intended to complement Section 2.2.2 and Table 2.1 by presenting the variable system in a more transparent and review-oriented format, thereby improving methodological clarity and replicability. Consistent with the research design, the variable system includes one dependent variable, one core explanatory variable, four mediating variables, and a set of control variables capturing firm characteristics, ownership structure, and financial conditions.

Variable Type	Symbol	Variable Name	Meaning	Calculation/Value	Main Data Source
Dependent Variable	ESG	Enterprise ESG Performance	Firm-level environmental, social, and governance performance	Huazheng ESG rating converted into numerical scores from 9 (AAA) to 1 (C); higher values indicate better enterprise ESG performance	WIND Database (Huazheng ESG rating)
Independent Variable	IM	Intelligent Manufacturing	Firm-level intelligent manufacturing capability / level	Firm-level intelligent manufacturing index constructed using panel stochastic frontier analysis (PSFA); higher values indicate higher intelligent manufacturing efficiency	CnOpenData Database
Mediating Variables	TRANS	Information Transparency	Degree of firm information openness and external observability	ln(1+number of financial analysts covering the firm in a given year)	CSMAR/ WIND Database
	GTI	Green Technology Innovation	Firm-level green innovation capability	ln(1+number of granted green patent applications identified by WIPO IPC green classification)	CSMAR/ patent database
	KZ	Financing Constraints	Degree of firm financial	Kaplan-Zingales (KZ) index	RESSET/ CSMAR/

			constraint in sustaining investment	constructed using cash flow, leverage, Tobin’s Q, dividends, and cash holdings; higher values indicate tighter constraints	financial statement data
	DEM	Synergistic Governance	Digitally enabled governance coordination capability	Digital Empowerment of Management (DEM) index capturing digital integration of management and governance processes	RESSET/ WIND/ corporate governance data
	SIZE	Firm size	Captures scale differences across firms	Natural logarithm of total assets	RESSET/ CSMAR Database
	LEV	Financial leverage	Captures firm debt burden and capital structure	Total liabilities divided by total assets	RESSET/ CSMAR Database
	ROA	Profitability	Captures internal earnings capacity	Net income divided by total assets	RESSET/ CSMAR Database
	TOP1	Ownership concentration	Captures the degree of concentration in corporate ownership	Shareholding ratio of the top 1 largest shareholder	WIND/ CSMAR Database
Control Variables	Age	Firm age	Captures organizational maturity	Number of years since firm listing	RESSET/ CSMAR Database
	SOE	State ownership	Captures ownership structure	Dummy variable equal to 1 if the firm is state-owned, and 0 otherwise	WIND/ CSMAR Database
	Year	Year fixed effects	Controls for macroeconomic shocks, policy changes, and time-specific factors	Year dummy variable	Constructed by the author
	Firm	Firm fixed effects	Controls for time-invariant firm-specific heterogeneity	Firm dummy variable	Constructed by the author

Appendix 15A Note on DEM Measurement and Standardized-index Representation:

The DEM index used in this dissertation is directly obtained from the relevant database and is used as a firm-year proxy for the Digital Empowerment of Enterprise Management. To improve measurement transparency, the standardized construction logic of the index can be expressed as follows:

$$DEM_{i,t} = \frac{1}{K}\sum_{k=0}^{k} Z_{i,t,k}$$

Where:

$$Z_{i,t,k} = \frac{X_{i,t,k} - min(X_k)}{max(X_k) - min(X_k)}$$

$DEM_{i,t}$ denotes the Digital Empowerment of Management index of firm *i* in year *t*. $X_{i,t,k}$ represents the original value of the *k*-th digital management-related item identified from database records and firm disclosures, including digital management systems, data-driven decision-making, information-sharing mechanisms, process coordination tools, intelligent office and operation platforms, and digital governance applications. $Z_{i,t,k}$ is the standardized value of $X_{i,t,k}$. *K* denotes the number of digital management-related items included in the index. A higher $DEM_{i,t}$ indicates a higher level of digital empowerment of management and stronger digitally enabled governance coordination capacity.

It should be noted that this dissertation does not manually reconstruct the DEM index from raw textual items. The formula is provided to clarify the standardization and aggregation logic of the database-based index and to improve the transparency of variable interpretation.

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1. Chen, X., & Batkhuyag, G. (2026). Research on the impact of intelligent manufacturing on enterprise ESG performance: empirical evidence of economics from China [J]. International Journal of Accounting and Economics Studies. E-ISSN: 2309-4508.
2. Chen, X., & Batkhuyag, G. (2026). Intelligent manufacturing as a driver of ESG performance: a multiple-case study of Chinese manufacturing firms [J]. Lecture Notes in Education, Arts, Management and Social Science. ISSN(Online): 2705-053X
3. Chen, X., & Batkhuyag, G. (2026). Does Intelligent Manufacturing Enhance Enterprise Esg Performance? Empirical Evidence from China. International Journal of Social Science and Economics Invention, 12(05), 34 TO 40. ISSN: 2455-6289
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