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Mechanisms, Heterogeneity and Practical Paths of Intelligent Manufacturing Driving Enterprise Innovation Capability Improvement

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Abstract

The new round of global scientific and technological revolution and industrial transformation is advancing continuously. Intelligent manufacturing has become the core driving force for China's manufacturing industry to complete transformation and upgrading and achieve high-quality development. This paper systematically sorts out several internal paths through which intelligent manufacturing helps manufacturing enterprises cultivate innovation capabilities, analyzing from the dimensions of digital technology application, internal organizational adjustment, simultaneous advancement of diversified innovations, and overall industrial chain transformation. Meanwhile, it distinguishes the differentiated effects under different operating entities, industry tracks, enterprise scales and matching degrees of development plans. The paper sorts out the common practical problems existing in the process of intelligent transformation of domestic manufacturing enterprises at this stage, including the disconnection between software and hardware construction, insufficient supply of digital skilled talents, insufficient linkage of various entities in the industrial chain, and the need to improve the accuracy of supporting support policies. Finally, it puts forward feasible development ideas from the government level and the enterprise itself respectively, providing theoretical reference for various manufacturing enterprises to cultivate innovation strength relying on intelligent transformation.

Keywords

Intelligent Manufacturing; Enterprise Innovation Capability; Digital Capability; Organizational Change; Supply Chain Collaboration.

1. Introduction

The relevant deployment of the 20th National Congress of the Communist Party of China clearly proposes to promote the high-end, intelligent and green development of the manufacturing industry, and intelligent transformation and upgrading is regarded as the core direction of building a manufacturing power. With the implementation of a series of supporting policies such as "Made in China 2025", the overall digital transformation progress of China's manufacturing industry has continued to accelerate. China's manufacturing added value has ranked first in the world for 14 consecutive years, accounting for about 30% of the global total in 2023. However, in the process of implementation, many manufacturing enterprises only attach importance to the investment in hardware equipment during the upgrading process, ignoring the simultaneous upgrading of software systems and internal management. Even if they purchase a large number of advanced production equipment, they fail to fully transform them into enterprise innovation strength and market competitive advantage.

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Existing academic achievements have analyzed the changes brought by intelligent transformation to enterprise innovation from different perspectives. Hou Cuimei conducted research around the level of digital application and confirmed that this element plays a transitional role between enterprise intelligent upgrading and innovation performance [1]. Lei Peng focused on analyzing the conduction effect brought by internal organizational adjustment of enterprises [2]. Wu Shan built a corresponding analytical idea for the parallel development of two types of innovations in enterprises [3]. However, most existing studies only carry out analysis on a single action path, lacking multi-dimensional logical integration, and at the same time, there is less discussion on the common practical problems existing in the process of industrial upgrading and implementation. Based on the above situation, this paper sorts out the internal logic of intelligent production driving enterprise innovation development, distinguishes the differentiated effects under different conditions, sorts out the current development obstacles and puts forward feasible development ideas, providing theoretical reference for the digital upgrading of the manufacturing industry.

2. Core Mechanisms of Intelligent Manufacturing Driving Enterprise Innovation Capability Improvement

Intelligent manufacturing is a new production mode formed by the deep integration of a new generation of digital technology and advanced manufacturing technology. Its improvement of enterprise innovation level does not rely on a single technology to play a role, but is a comprehensive effect brought by the simultaneous adjustment of technology, organization and industrial ecology.

2.1. Digital Capability Empowerment

If manufacturing enterprises want to produce innovative results with the help of intelligent production technology, they cannot do without comprehensive digital-related capabilities as basic support. This capability can be distinguished from three levels: production equipment, employees and internal management. After the introduction of intelligent sensors, automation equipment and digital simulation tools at the production equipment level, the operation data of the entire production line can be completely collected. Relying on massive and accurate data to optimize processes and develop new products, the trial-and-error cost in the innovation link is greatly reduced. At the employee level, traditional front-line operators have gradually transformed into compound practitioners who master digital tools and manufacturing processes [4]. They can carry out innovative exploration relying on industrial software and data analysis tools, and combine years of on-site practical experience with digital technology. At the internal management level, an integrated online operation platform is built to break the state of information isolation between various departments, accelerate the circulation speed of innovative resources, and facilitate cross-departmental staff to carry out innovative work jointly. Existing survey data show that most enterprises have only completed the digital transformation of production equipment, the digital adjustment of internal management links is progressing slowly, and the value that digital management can play has not been fully released.

2.2. Organizational Capability Reshaping

Implementing intelligent production is not just about replacing production equipment, but also requires the internal organizational mode of enterprises to make adjustments simultaneously. The level of an enterprise's own organization directly determines whether intelligent technology can be transformed into innovative results. Lei Peng's research confirmed that various adjustments at the organizational level form a key conduction channel between intelligent transformation and enterprise innovation performance [2]. It is specifically reflected

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in three aspects: First, data assists enterprises in completing business judgments, more accurately discovering innovation opportunities, rationally allocating R&D resources, and ensuring the steady progress of innovation projects. Second, the interconnection of equipment breaks the functional boundaries between various departments. Enterprises set up cross-departmental working groups, which makes it easier to identify external new technologies and new knowledge and transform them into their own resources. Third, a unified data platform combined with intelligent analysis tools simplifies the entire innovation process, shortens the cycle from idea implementation to product mass production, and enterprises can respond faster to changes in market demand.

2.3. Dual Innovation Coordination

After the simultaneous implementation of digital technology and intelligent equipment, enterprises can simultaneously promote the optimization of original processes and the exploration of new technologies, taking into account short-term benefits and long-term development. On the one hand, existing products and mature processes can be rapidly iterated and upgraded with the help of intelligent production lines, mining more value on the basis of existing technologies, and stabilizing the short-term operating income of enterprises. On the other hand, big data and artificial intelligence tools can tap potential market demand, support enterprises in carrying out cutting-edge technology R&D, and open up new business tracks. Intelligent manufacturing brings sufficient resources and supporting tools to help enterprises balance the two tasks of improving existing businesses and exploring new directions, avoiding the two extreme development ideas of enterprises only focusing on mature businesses for a long time or blindly investing in new fields.

2.4. Supply Chain Collaborative Upgrading

The traditional linear supply mode of upstream and downstream has gradually transformed into a multi-party linked industrial network. Intelligent technology promotes manufacturing enterprises to jointly build an open innovation environment with upstream and downstream enterprises and scientific research institutions [5]. The industrial online platform opens up the data channels of various entities in the industrial chain. Enterprises can timely grasp the two types of information of upstream raw material supply and downstream market demand, making innovative R&D close to the real market needs. Upstream and downstream enterprises carry out joint product R&D relying on the online platform, share innovation investment and market risks together, and share various benefits brought by R&D. At the same time,

intelligent manufacturing involves a large number of cutting-edge technologies, and it is difficult for a single enterprise to complete all research and development work. Therefore, manufacturing enterprises will actively connect with universities and research institutes to jointly break through key industrial technologies and drive the overall improvement of the innovation level of the entire industry.

3. Heterogeneity Characteristics of Intelligent Manufacturing Affecting Enterprise Innovation Capability

Different enterprises have obvious differences in resource reserves, industries, operation scales and development plans, and the improvement effect of intelligent transformation on innovation level will also show obvious differences.

3.1. Property Right Nature Heterogeneity

There are obvious differences in innovation output between state-owned operating entities and private operating entities after promoting intelligent upgrading. Relying on policy support, state-owned enterprises are more likely to obtain special subsidies and long-term credit funds,

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which are suitable for investing in long-cycle large-scale intelligent production line construction and core technology research projects. However, the internal assessment and incentive mechanisms of some state-owned enterprises are not perfect, the internal decision-making process is long, and the speed of transforming technology investment into innovative products is relatively slow. Private enterprises face stronger market competition pressure, have more flexible operating mechanisms, can quickly adjust R&D directions according to market changes, and the innovation improvement effect brought by intelligent upgrading is more intuitive. However, private enterprises generally have the problem of limited capital reserves, and it is difficult to independently carry out long-cycle and large-investment basic technology research.

3.2. Industry Type Heterogeneity

Different industries have different accumulated technical reserves and different demand degrees for intelligent transformation, and the final innovation improvement effects are also different. High-end manufacturing industries such as mechanical equipment, electronic manufacturing and new energy vehicles themselves have sufficient technical reserves. After the implementation of intelligent equipment, they can rapidly iterate core technologies, and the output speed of industry innovation achievements is fast. While traditional manufacturing industries such as textile and basic processing have weak technical accumulation themselves, upgrading requires a lot of capital and talents, and the overall innovation improvement range is limited. Some enterprises blindly purchase intelligent equipment without carrying out transformation combined with their own product characteristics, resulting in low input-output ratio.

3.3. Enterprise Scale Heterogeneity

The size of an enterprise directly determines the capital and talent reserves that can be invested in intelligent upgrading. Large enterprises have abundant funds, can recruit various professional and technical personnel, have the ability to integrate the resources of the entire industrial chain, build an intelligent system covering all links of R&D, production and sales, and all links of innovation work can be promoted simultaneously. Small and medium-sized manufacturing enterprises have limited capital reserves, and most can only carry out local digital transformation for a single production link, making it difficult to build a complete intelligent system. At the same time, they lack professional digital technical staff, and various functions of intelligent equipment cannot be fully utilized, so the driving effect on innovation is weak.

3.4. Strategic Matching Heterogeneity

Whether the overall development plan of an enterprise matches the direction of digital transformation directly determines how much value intelligent technology can play. Hou Cuimei's research confirmed that the higher the fit between the overall enterprise plan and digital transformation, the more obvious the driving effect of intelligent upgrading on innovation [1]. When enterprises make overall arrangements for digital transformation and long-term development, talent training and technology R&D plans, various resources can be reasonably allocated, and technology investment can be smoothly transformed into innovative output. If digital transformation is only a short-term project and not integrated into the long-term development arrangement of the enterprise, it is easy to have chaotic resource allocation and it is difficult to continuously improve its own innovation strength.

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4. Existing Challenges of Intelligent Manufacturing Improving Enterprise Innovation Capability

The large-scale promotion of intelligent transformation in China's manufacturing industry has achieved many results, but there are still multiple obstacles in the implementation process, which restrict the continuous improvement of enterprise innovation level.

4.1. Transformation Misunderstanding of Disconnection between Technical Transformation and Organizational Adjustment

A large number of enterprises only focus on equipment procurement when carrying out digital transformation, ignoring the simultaneous adjustment of internal management systems, organizational structures and corporate culture [6]. The traditional multi-level management mode has slow information transmission speed and obstacles to cross-departmental collaborative innovation. Even if equipped with intelligent equipment, it is difficult to quickly adjust R&D directions according to the market. At the same time, many enterprises have not formed a working atmosphere adapted to digital operations, and the acceptance of staff to new operation modes is low, so the value of advanced equipment cannot be fully released.

4.2. Serious Shortage of Digital Talent Supply

The mismatch between the skills mastered by employees and the capabilities required by intelligent production is a key factor restricting enterprise innovation. At present, there is a large gap in domestic compound practitioners who master both manufacturing processes and digital tools. Front-line workers who have been employed for many years are familiar with production processes but lack skills related to data analysis and intelligent equipment operation; young employees are familiar with various digital software but lack on-site manufacturing practical experience, making it difficult to combine digital tools with production processes. Relevant industry survey data show that 70% of enterprises carrying out intelligent transformation have a gap in digital skilled talents, and the talent shortage in equipment operation and maintenance, data modeling and other positions is the most prominent.

4.3. Low Level of Supply Chain Collaborative Innovation

The digital perfection degree of China's entire industrial chain is uneven, and the data interconnection rate between upstream and downstream enterprises is less than 45%. Each enterprise operates independently and information is not connected. Most enterprises' digital transformation is only limited to their own factory areas, and they have not opened up data channels with upstream and downstream enterprises, resulting in low overall innovation efficiency of the industrial chain. At the same time, various entities in the industrial chain lack a stable joint R&D mechanism, and innovative resources are difficult to circulate and allocate within the industry, making it difficult to form a development situation of full-chain synchronous innovation.

4.4. Need to Improve the Accuracy of Policy Support

At this stage, the policy resources supporting intelligent transformation are mostly inclined to large high-end manufacturing enterprises, and small and medium-sized manufacturing and traditional industries can get less support resources. Small and medium-sized manufacturing enterprises have weak anti-risk ability and limited capital reserves, and lack special subsidy support, so the digital transformation progress is slow. In addition, some support policies only focus on fund distribution, lack of follow-up tracking of implementation effects. Some enterprises carry out transformation simply to obtain subsidies, without planning projects combined with their own innovation needs, making it difficult for capital investment to be transformed into new products and new processes.

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5. Conclusion and Policy Implications

5.1. Research Conclusion

Intelligent production mode is the core driving force for manufacturing enterprises to improve their innovation strength. Relying on several paths of digital technology implementation, enterprise organizational adjustment, parallel multi-type innovation and overall industrial chain transformation, it comprehensively improves enterprise innovation output from multiple levels of technology, organization and industry. At the same time, the innovation improvement effect brought by intelligent upgrading will vary significantly with enterprise property rights, industries, operation scales and development plans. At present, the promotion of intelligent transformation by domestic manufacturing enterprises still faces practical obstacles such as lagging organizational adjustment, shortage of compound talents, insufficient industrial chain linkage and insufficient pertinence of support policies. It requires the simultaneous efforts of both the government and enterprises to promote the deep integration of digital transformation and innovation cultivation.

5.2. Policy Implications

From the perspective of government work, first, implement differentiated support plans, increase support for traditional industries and small and medium-sized manufacturing enterprises, alleviate capital pressure through tax reduction and exemption, special low-interest loans, financing guarantees and other methods, and set up special funds for local digital upgrading of small and medium-sized enterprises. Second, improve the compound talent training system, promote universities and factories to jointly build training platforms, carry out regular digital skills training for on-the-job employees, and fill the industry talent gap. Third, build an industrial chain linkage development environment, support the implementation of cross-industry industrial online service platforms, open up data channels between upstream and downstream enterprises, encourage industry leaders to drive supporting small and medium-sized enterprises to complete digital transformation simultaneously, and carry out joint R&D work. Fourth, improve the whole-process supervision of support projects, build a digital upgrading effectiveness evaluation mechanism, track the use effect of subsidy funds, and improve the efficiency of policy fund utilization.

From the perspective of enterprise operation, first, give consideration to equipment upgrading and internal adjustment. While purchasing intelligent equipment, simultaneously simplify internal management levels, optimize business processes, create a working atmosphere adapted to digitalization, break departmental barriers and form joint innovation teams. Second, steadily improve comprehensive digital-related capabilities, carry out targeted transformation of production and management links combined with their own product characteristics, organize regular digital skills training for employees, and build an incentive system linking skill assessment with promotion. Third, coordinate digital transformation and long-term enterprise development plans, clarify upgrading goals and phased implementation plans, let digital transformation serve the overall business direction, and avoid blind investment. Fourth, actively connect with upstream and downstream enterprises in the industrial chain, universities and scientific research institutions, carry out joint R&D relying on online platforms, and build a multi-party participating innovation cooperation environment.

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