Impact of Intelligent Manufacturing on Total-Factor Energy Efficiency

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Intelligent technology is the core driving force of the fourth industrial revolution, which has an important impact on the high-quality economic development. First, the productivity effect, scale effect and resource allocation effect of intelligent manufacturing can significantly improve the energy efficiency of total factor, and the conclusion is still established after endogenous treatment and robustness test. Second, the results of the action mechanism show that labor price distortion and carbon emission trading policy are important mechanisms for intelligent manufacturing to improve total factor energy efficiency.

Keywords: intelligent manufacturing ; total-factor energy efficiency ; TFEE

1. Introduction

Energy is an important cornerstone of economic and social development. Since the reform and opening-up, the China government has unswervingly pushed forward the energy revolution, and the method of energy production and utilization has undergone significant changes, basically forming an energy supply system driven by coal, oil, gas, electricity, nuclear energy, new energy and renewable energy and making historic achievements in the energy industry. Since the 19th National Congress of the Communist Party of China, the CPC Central Committee has paid more attention to the energy revolution and proposed adhering to the new development concept, building a clean, low-carbon, safe and efficient energy system, and taking firm steps in building a beautiful China. High-quality development is leading China's economic development. When entering a new era, China's economy faces the problem of achieving better development. After years of rapid development, the constraints of resources, environment and population on economic development are becoming increasingly obvious. The extensive development model of "three highs and one low" in the past has been exhausted, which is not conducive to sustained and healthy economic development. At the same time, the energy structure of "rich in coal, poor in oil and less in gas" makes China fall into the dilemma of passively adapting to international energy trade and environmental governance rules. Economic development faces the dual constraints of environmental pollution and energy shortage, and energy security is vulnerable to threats. As the primary input factor of economic development, energy plays a vital role and has been regarded as an essential economic growth booster. China is the world's largest energy consumer, and especially under the premise of the significant price advantage of coal, it will be difficult to reverse the consumption structure of coal for a long time in the future. In 2020, China imported 303.99 million tons, up 1.5% yearly; crude oil imports were 542.39 million tons (including 28.35 million tons of refined oil products), up 7.3% year on year, and overall energy imports have shown an upward trend in recent years. This means that it is still difficult to address the short- and medium-term energy constraints by increasing the proportion of renewable and clean energy consumption. In this regard, the report of the 19th CPC National Congress pointed out that "improving total factor productivity is an important and reliable path to achieve high-quality economic development." How to improve total-factor energy efficiency (TFEE), effectively control the total energy consumption and complete the "14th Five-year Plan" unit GDP energy consumption reduction target of 13.5% has become the urgent proposition of the present time.

Wright first put forward the concept of "intelligent manufacturing," pointing out that intelligent manufacturing is a process in which intelligent robots complete small batch production by themselves without human intervention by integrating knowledge engineering, manufacturing software systems, and robot vision [7]. With the acceleration of the new wave of the digital and intelligent technological revolution, IM has been endowed with new connotations in its development. With the joint development of its related advanced manufacturing concepts such as computer-integrated manufacturing, flexible manufacturing, and agile manufacturing in recent decades, the concept of "intelligent" in IM has been upgraded and broadened from the original narrow sense of "digital" to the current "digital, networked and intelligent. In addition to automatic and unmanned production, the more profound role of IM lies in helping enterprises to realize mass production to customized production through its "Prosumption" mechanism, which not only improves production efficiency but also optimizes resource allocation. IM can be understood as combining the new generation of information technology with advanced automation, sensing, control, digital, and management technology in a highly flexible and highly integrated way at all stages of the manufacturing industry. It also supports the real-time management and optimization within and between factories and enterprises, as well as the whole life cycle of products (product development and design, production and processing, operation management, maintenance service, and scrap disposal). As there is no unified definition of IM, scholars draw lessons from the Development Plan of Intelligent Manufacturing (2016–2020). It holds that IM is a new mode of production with the functions of self-perception, self-learning, self-decision-making, self-execution, and self-adaptation based on the deep integration of the new generation of information and communication technology and advanced manufacturing technology, which runs through all aspects of manufacturing activities such as design, production, management, and service.

In green and low-carbon development, the energy industry is the main battlefield. Improving TFEE becomes the most feasible and realistic means of achieving green economy goals in the short term. However, the current single-terminal governance model has struggled to meet the demand for improving TFEE. The integration of digital technology and natural economy development is becoming a realistic choice to reshape the competitiveness of high-quality development. The intelligent system relies on deep learning, independent decision-making, and dynamic monitoring, which can effectively and quickly provide countermeasures and help the upstream links such as raw material supply, intermediate goods transportation, and energy production to connect efficiently, which not only saves the time cost, transaction cost and transportation cost of enterprises, but also draws a more reasonable blueprint for energy supply on this basis, and improves the comprehensive utilization efficiency of energy in the whole city. According to the data of “World Robots 2021 Industrial Robots” released by the International Federation of Robotics (IFR), in 2020, nearly 168,000 industrial robots will have been newly installed in China, accounting for 43.8% of the world, and the level of automation and intelligence in the manufacturing industry is increasing day by day. The research report “Accelerating Energy Transformation by Using Artificial Intelligence,” released by the World Economic Forum in 2021, pointed out that artificial intelligence technology has great productivity in the process of energy decentralization, digitization, and decarbonization, and it has strong application in renewable energy generation capacity and demand forecasting, power grid operation and optimization, energy demand, and distributed resource management. The report “Digital Energy 2030” released by Huawei also pointed out that digital technology can make the intelligent evolution of energy systems and promote the maximization of energy value, which is the core “pry point” to drive the transformation of the energy industry. From the perspective of intelligent manufacturing, exploring its impact on TFEE is of great reference value for ensuring national energy security, achieving the goal of “double carbon,” and accelerating the construction of energy power.

2. Impact of Intelligent Manufacturing on Total-Factor Energy Efficiency

2.1. The Mechanism Analysis of IM Affecting TFEE

Productivity effect: TFEE reflects the input–output efficiency of electric energy, coal, oil and natural gas in production and life. Technological progress means expanding the forefront of production through technological improvement, human capital accumulation and organizational management efficiency improvement, so as to improve the maximum output capacity under the established factor combination input. A typical example of the “digital intelligence” of the real economy is the rapid popularization and large-scale application of intelligent robots in the industrial sector. By introducing big data in the process of traditional production and modern digital technology such as artificial intelligence, “intellectualization” can effectively improve the operation efficiency of different factors of production configuration combination to realize the traditional factors of production of marginal output, help traditional enterprises “old tree sprout”, and fully promote the real economy sector to adapt to the new requirements of digital economy development. As the IM of neutral technology progress, it naturally carries the penetration, synergy, and substitution characteristics of digital technology, which can penetrate all fields of social life. On the one hand, the existence of Moore’s Law makes the chip-based, digital and information-based products constantly updated, and the prices of related products will also drop rapidly with the change and popularization of technology, which will help related manufacturers to gradually phase out production equipment with high energy consumption and low efficiency, thus reducing energy consumption and improving marginal energy productivity. On the other hand, related industry standards and customer demand will be improved with the improvement of labor productivity, process technology, and production process. More stringent factory standards and high-level market demand will lead to the derivative demand of enterprises for high efficiency, cleanliness, and high quality. Therefore, enterprises can hedge the negative effects of increasing production costs and intensifying market competition by reducing total energy consumption, using intensity, and improving energy utilization efficiency.

Scale effect: The most striking feature of emerging technologies is to replace low-skilled labor and supplement high-skilled labor. This will relieve the dependence of enterprises on labor factors through digitalization, informatization, and intelligence, quickly complete the repetitive tasks of packaging, sorting, and transit that human labor cannot complete in a short time, and use the same energy consumption and labor to obtain greater economic output, to improve the total factor productivity of enterprises. IM, in the process of intelligent activities, involves the collaborative interaction and cooperation of people and intelligent machines and uses the concept of automation for flexible, intelligent and highly integrated working, so as to realize traditional factory to digital factory transformation, which makes manufacturing enterprises, through digital development, improve product quality and management efficiency. A mature, intelligent manufacturing factory or enterprise often does not simply transform its production equipment intelligently but integrates market demands and consumer demands into production processes and product design. All aspects of product production are connected in series with the help of intelligent products, intelligent design, intelligent production, and intelligent management. Enterprise managers use technologies such as the Internet and the Internet of Things to realize horizontal integration and vertical expansion of intelligent production, and then use mobile communication technology and intelligent equipment to realize digital transformation of the whole intelligent production value chain, thus forming and smoothing the whole intelligent management system. Enterprises also introduce industrial robots and high-tech talents, expand production scale, promote the continuous improvement and extension of related industrial chains and supply chains through economies of scale, and improve resource utilization efficiency.

Resource allocation effect: IIM can reduce energy consumption per unit output and improve comprehensive TFEE. A typical example is that the traditional energy industry only pays attention to watt flow, and the nodes of power generation, transmission, distribution, storage, and use are isolated, making it cooperate, resulting in low operating efficiency of the energy system. Moreover, there are many “dumb devices” in the full link, and the operation and maintenance efficiency are low with manual maintenance. IM digitally processes energy by introducing digital technologies such as 5G, AI, and big data, innovatively integrates power electronics technology with digital technology, adds bit streams based on watt flow, and manages watts with bits to realize complete link interconnection, digitization, and intelligent collaboration and to maximize power production efficiency, equipment operation and maintenance efficiency and TFEE. In addition, at the present stage, the world’s energy system is undergoing structural restructuring and map reconstruction: centralized and decentralized variable renewable energy is incorporated into the power grid, the electrification trend of energy consumption is becoming increasingly prominent, and consumers involved in production activities are emerging. Energy demand flexibility features increasingly emphasize the timeliness and efficiency of the energy supply. Energy digitization enables intelligent buildings, transport, vehicles, and industrial facilities to provide new flexible load sources for energy systems, helping suppliers cut energy supplies and supporting communities to better consume the energy they produce. By improving the use efficiency of end users and system efficiency, the entire energy system will benefit from avoiding repeated investments in energy facilities, reducing ineffective losses in production and distribution, optimizing the combination of renewable resources, and enhancing energy security. As a general progression in technology, IM itself represents typical non-competitive public goods. When it performs innovation activities in a certain area, it will often produce “energy technology diffusion” and “energy technology spillover”, that is, the unconscious outflow of technological innovation and the unconscious acceptance of relevant subjects. The spillover effect of IM is specifically manifested in the embedding of the automation technology of machinery and equipment into the application department, realizing the interaction between factor input and science and technology in the production link, and then promoting the production, transportation, storage and consumption to form a new enterprise production mode and the new energy technology and equipment, energy conservation and environmental protection awareness. At the same time, the artificial intelligence platform contributes to the sharing of data elements. With the help of factor circulation and knowledge technology spillover, it builds an intelligent management system of energy interconnection and global energy allocation network and integrates traditional chimney independent system architecture and remote island management into a unified architecture, unified management, and comprehensive application to realize overall planning, coordination, and optimization of the whole link, thereby promoting low-carbon development of the whole society and improving energy utilization efficiency. The combination of artificial intelligence technology and traditional factors of production can effectively improve the allocation quality and combination efficiency of the original factors of production by expanding the application scenarios of digital energy and upgrading digital management, thus enhancing the coordination of organization and management of production enterprises and the overall efficiency of factors. For example, Datang Group Co., Ltd. (Beijing, China), China realizes a 3D virtual power plant through advanced communication technology and software architecture and realizes the aggregation, coordination, and optimization of spatial and geographical dispersion. Its intelligent control system controls the power production process in real-time and completes energy storage and rational allocation. Accordingly, The productivity effect, scale effect and resource allocation effect of IM carrying can improve the TFEE.

2.2. The Intermediary Path of Labor Price Distortion

In the neoclassical economic growth theory, the primary source of total factor productivity improvement lies in technological progress and resource allocation efficiency. The price mechanism is the essential reflection of the allocation of resources in the market economy. However, the distorted factor price cannot truly reflect the scarcity degree and the relationship between the supply and demand of resources in the factor market. Factors of production are the starting point of the economic cycle, and the distortion of factor price will affect the macroeconomic variables such as consumption, investment, total output and total factor productivity by affecting the efficiency of resource allocation. The loss of production efficiency caused by ineffective factor allocation or overcrowding is considered an essential factor in reducing the efficiency of resource allocation and even the welfare of residents in a country. Moreover, existing studies find that the contribution of the improvement of factor allocation efficiency to the improvement of total factor productivity is improved. The labor factor has strong initiative and adsorption and is an important link to other factors of production, knowledge, technology, management, and data elements attached to the labor itself and through the labor bridge to achieve activation and operation. However, the distorted labor market not only may make the resource allocation imbalanced between enterprises but will also stop the efficient enterprises entering the market, therefore producing greater efficiency loss.

Currently, China's labor price is mainly manifested as low price distortion, the remuneration of labor suppliers is lower than the marginal contribution, and the price distortion in less developed areas is severe. Underestimated labor remuneration will enable enterprises with low production efficiency to use many tangible low-cost factors to obtain more profits. The arbitrage space formed by it will lead to a large number of laborers flowing to extensive production projects with quick results and low uncertainty, which will make economic growth stand out as factor-driven epitaxial growth, aggravate the low-end lock-in of industrial structure, and is not conducive to the improvement of TFEE in the production process . As far as labor price distortion is concerned, negative price distortion causes enterprises to have the illusion that labor elements are vibrant, and then they will hire cheaper labor. This price advantage of low-cost labor reduces the demand of enterprises for capital factors and technological innovation attached to capital goods, which makes managers stay in low-end production links for a long time, resulting in a low contribution of technological progress to TFEE. In addition, the distortion degree of labor factors is different in different regions, and there is regional heterogeneity in the distortion degree of factor prices. This difference will cause the price of labor factors in some areas to be seriously underestimated, which will enable those enterprises that should have been eliminated by the market to continue their production and business by moving and transferring to lower-cost areas. This aggravates the dilemma of low-end locking of industrial structure in those areas where labor-intensive industries are the leading industries, and it is difficult to develop the rationalization and upgrading of industrial structure, which is not conducive to technological progress and the improvement of TFEE.

Guiding the labor force with higher human capital to flow to the regions, departments, and industries with advanced productive forces will help to improve the total factor productivity. IM has substantial advantages in correcting the distortion of the labor factor market, unimpeded factor channel, and strengthening the efficiency of resource allocation. First, the rapid development of intelligent technology with the underlying logic of IM helps to reduce the cost of information search and simplify the collection path. With the help of Internet technology, workers can collect, sort out, compare and analyze information such as job salary, skill demand, and labor demand to form accurate information about the rationality of labor remuneration and help reduce market information asymmetry. At the same time, they can simplify the market transaction business process and improve the information transparency of the transaction process to form a nationwide network transaction system, to a certain extent, to reduce the market segmentation formed by local protectionism and administrative barriers and to reduce price distortion. Second, the Internet technology-derived network platform has weakened the physical barriers of distance and time, information can be spread more quickly across regions and across time, cross-sectoral transmission and sharing can occur, element demanders and labor suppliers can combine their expectations in broader market-accurate matching, saving transaction cost time, thus opening free flow channels for labor elements, and the level of factor–market integration can be improved. New online working methods, such as telecommuting, online meetings, and remote services, enable workers to participate in the division of labor in the whole of society without changing their residence and workspace, forming invisible mobile labor, and following the trajectory of a low rate of return to a high rate of return, therefore reducing price distortion. Third, the market impact of IM on employment is mainly produced through productivity efficiency, compensation effects, and destructive effects. IM technology uses technological advantages and capital advantages to replace conventional, programmable rules of labor, and human labor has the comparative advantage of new tasks, economic activities, and work forms being constantly created; different skills of workers in the digital technology leads to the higher efficiency of the digital industry and needs to be implemented in emerging jobs to achieve efficient matching and obtain more reasonable labor remuneration. Accordingly, IM can improve TFEE by mitigating labor price distortions.

2.3. The Moderating Effect of the Carbon Emission Trading Policy

Coase Property Rights Theory shows that under the premise that property rights can be clearly defined, spontaneous market transactions can realize the Pareto optimal resource allocation. The profound logic of carbon emission trading policy is the commercialization, asset, and data of carbon emission rights. By limiting control of enterprise greenhouse gas emissions and emission quotas, with the help of market mechanisms to transform environment negative external cost into enterprise internal production costs, this reverses transmission control to complete the performance conditions, promotes the carbon market to reach the Pareto optimal situation, and finally realizes the quality and efficiency of energy utilization, energy conservation and emission reduction of the whole economy and society. An appropriate and reasonably designed environmental regulation policy will promote the constrained individuals to stimulate the consciousness of technological innovation under limited conditions, dynamically integrate the factor input combination, and improve the green total factor productivity. The carbon emission trading policy releases the guiding signal of environmental regulation, and the diffusion of its policy influence can not only promote energy reform, consumption revolution, and the green industrial system through the “pilot diffusion” under superior administrative instruction and promote the improvement of the green low-carbon cycle development economic system, but it can also guide and encourage scientific research and development and technological innovation, expand the application scenarios of advanced green technology, and promote the “active diffusion” self-organization after learning and imitation in non-pilot areas . As a means of market-oriented environmental regulation, carbon emission trading policy impacts TFEE in three ways: cost pressure, policy guidance, and interest incentive. Specifically, according to the requirements of carbon emission intensity regulation, the government issues a certain free emission quota to each market participant with the carrier of the “carbon emission permit” system. Regulators who exceed the quota need to buy carbon emission quotas in the trading market, and enterprises with carbon reduction advantages can sell carbon emission rights or transfer green technologies as profits. Based on the consideration of controlling emission costs and removing fossil energy consumption dependence, the original energy-intensive enterprises will independently carry out energy conservation and emission reduction, increase green technology research and development, continuously optimize the production process, improve production technology, and replace and eliminate backward equipment, thus bringing higher TFEE. At the same time, policy instructions’ long-term, mandatory, and supportive characteristics will optimize the distribution mode and correlation of production factors among industries. Carbon trading policy released green market signals to guide capital, technology, talent, energy, and other elements to the low-carbon industry. The original energy-intensive, high-carbon-emission old industry, due to pressure from environmental constraint pressure, has been forced to change into a green, high-efficiency, low-carbon new industry. The direct impact is that a region will eventually undergo advanced industrial structure change, while reducing carbon emissions and improving TFEE. As an essential booster of low-carbon transformation, with deep integration among the digital network, “Metcalfe Law”, advanced intellectualization technology and traditional power, energy, and transportation industries, can effectively assign enterprises green IM and energy management, lead the green industry and process reengineering, promote the critical carbon industry’s whole lifecycle of energy consumption, and realize TFEE and the production efficiency of double promotion. Moreover, digital technology helps administrative departments to find out the “carbon background”, carry out “carbon investigation” and “carbon planning” under the background of carbon emission regulation, and significantly enhance the government departments to monitor urban carbon emissions and low-carbon governance capacity. Therefore, in improving TFEE by IM, carbon emission trading policy mainly forces industrial upgrading and low-carbon transformation by imposing environmental pressure on “three high” enterprises to further weaken enterprises’ dependence on energy consumption and ultimately improve TFEE. Based on this, the carbon emission trading policy will strengthen the positive effect of IM on improving TFEE.

3. Conclusions and Policy Implications

With the accelerated innovation of digital technologies such as big data, cloud computing, blockchain, and automation, the free flow of various production factors and the deep integration of various market entities have been promoted in recent years. The application of industrial robots is a concrete reflection of the integration of artificial intelligence technology and industry. Its extensive promotion and popularization in the manufacturing field not only bring about a change in production mode but also significantly impact the method of resource combination and energy utilization efficiency.

(1) The productivity effect, scale effect and resource allocation effect produced by IM technology can significantly improve the TFEE, and the conclusion is still valid after the robustness test and dealing with endogenous problems.

(2) LPD and CEPT are important mechanisms for IM to improve TFEE. On the one hand, IM helps to eliminate workers’ information search costs and search process, promote labor factors in a broader market configuration, more efficiently match labor supply and job demanders, and ease labor price distortion, and corrected LPD can strengthen the enterprise research and development and innovation and crack regional industrial structure low-end locking, ultimately improving the TFEE. On the other hand, CEPT, by imposing cost pressure on enterprises and supplemented by policy guidance and interest incentive, can strengthen enterprises’ willingness to develop green technology research and development, optimize the process, and replace backward equipment, so as to positively regulate IM and improve TFEE.

Policy Enlightenment

In order to give full play to the driving role of intelligent manufacturing in improving TFEE as much as possible, combined with the research perspective and conclusion of this paper, the following policy suggestions are put forward:

(1) Government departments should deepen the reform of IM systems and continuously improve the business environment of the digital economy. First, scholars will give full play to the role of the government in the top-level design and deepen the reform of the government management system. Starting from the perspective of industrial integration systems, scholars will expand the coverage space of intelligent manufacturing policy support, plan intelligent manufacturing production, equipment, technology, management, and other fields, and improve the policy system of intelligent manufacturing. At the same time, the government's policy preference for intelligent manufacturing should be based on the principle of "market leading, government guidance", give full play to the decisive role of the market in the allocation of intelligent manufacturing resources, and promote the rapid development of intelligent manufacturing industry. Second, scholars should increase the financial support for the development of intelligent manufacturing and deepen the reform of the financial system. scholars should implement the particular policy of preferential tax treatment for intelligent manufacturing enterprises, including the R&D expenditure of intelligent manufacturing technology in the list of VAT deductions to encourage intelligent manufacturing enterprises to strengthen independent innovation and carry out deep cooperation with the government in capital and technology, so that enterprises can reasonably enjoy the policy dividend. Third, scholars will optimize the talent supply and training structure, deepen the reform of the talent system, and alleviate the mismatch between labor industries and regions. On the basis of improving the supporting policies for talent introduction, the government builds a training platform for intelligent manufacturing talents and attracts foreign high-tech talents to reflux by improving economic treatment, politics, treatment, family treatment, and other forms. At the same time, scholars will support institutions of higher learning and vocational colleges to set up intelligent-manufacturing-related majors or practical courses, promote the construction of this discipline at different levels, and reserve sufficient professional talents for intelligent manufacturing enterprises and scientific research institutes. Fourth, scholars will promote the construction of a digital government to release the information dividend. With the implementation of e-government and the construction of a smart city as the starting point, scholars must integrate digital government into the digital transformation of the whole city, jointly promote the construction of a digital government and an innovative city, digital community, and digital countryside, and build the construction of a coordinated linkage represented by "three integration and five spans." Using digital intelligence to drive the system remodeling, scholars must actively explore data governance and government function reform, restore the "business flow" with departmental "data flow," promote the integration of government service links and process optimization of government services, realizing the "one network" of government services and leading the digital development with the construction of digital government. Fifth, scholars should accelerate the establishment of a multi-functional and integrated national carbon trading market data-sharing platform. The scholars will continue to pilot carbon trading in parallel with the national carbon market and give full play to the positive regulatory role of carbon emission trading policies. It is necessary to make full use of intelligent manufacturing, artificial intelligence, and blockchain advanced information technology, and optimize and integrate Guangdong carbon trading, China carbon city, Shenyang Carbon trading, and other local carbon trading user terminal information platforms, building a national-integrated, multi-functional carbon trading user terminal and data analysis platform and striving to eliminate information barriers.

(2) Governments must make breakthroughs in the core technologies of intelligent manufacturing and strengthen the strategic layout. First, they must strengthen basic industrial research to seize the advantages of intelligent manufacturing technology. With the industrial and supply chains as the main lines, scholars will make significant breakthroughs in the "five new types of infrastructure" engineering, industrial production, and application in essential fields such as intelligent equipment and new materials and constantly improve the essential capacity of intelligent manufacturing. scholars must strengthen the construction of industrial Internet infrastructure in public places and intelligent manufacturing industrial agglomeration parks, strengthen information security control, and promote the integration and interaction of manufacturing technology and information technology in all links of industrial manufacturing. Second, scholars will strengthen our strategic layout and give full play to its exemplary and leading role. Administrative departments can build regions and industrial parks with a good foundation of intelligent manufacturing into intelligent manufacturing demonstration bases and adopt the "reveal the list and take the lead" approach to concentrate high-end national resources, taking the lead in breaking through the key core technologies that restrict the development of intelligent manufacturing, to give full play to the positive leading role of pilot demonstration projects. At the same time, the leading enterprises of intelligent manufacturing should accelerate the cooperation of domestic and foreign universities and scientific research institutions, build an industrial innovation platform, and drive the upstream and downstream linkage and cooperation of the industrial chain and innovation chain. Third, scholars must learn lessons from advanced foreign experience to develop intelligent manufacturing essential software. For the weak link of the intelligent manufacturing essential software industry in China, a

software development-related support policy encourages industrial enterprises and software development park building technology demand communication platform, real-time tracking enterprise demand to jointly develop intelligent manufacturing basic software and operating system, solve the problem of software system development lags behind the intellectual level of China.

(3) Enterprise must build “intelligent” employees in the digital era and build a community of interests. First, scholars must reshape the corporate culture of the digital age through thinking. Intelligent manufacturing enterprises should give up the traditional top-down, inside-out planning and control mechanism, break the status quo of hierarchical decision-making, and change the enterprise development from “controlling employees” to “trusting employees.” At the same time, all levels embed the thinking mode of risk-taking and innovative development to cultivate a corporate culture with digital vision and genes. Second, scholars should carry out “online + offline” digital training and create a scientific training evaluation system. Intelligent manufacturing enterprises should drive data-driven enterprise learning and set up personalized and specific training courses. At the same time, using various management software and data analysis functions, these enterprises should establish a scientific training evaluation system, link the training content with employee performance, and fully mobilize employees’ enthusiasm to integrate into the digital age. Third, scholars should pay attention to individual value and realize the symbiosis of enterprise and employee value. Intelligent manufacturing enterprises should pay attention to organizational performance goals and consider the value of employees in the organization. Enterprises should establish a value platform shared by employees and organizations, constantly strengthen the communication between employees and other high-tech enterprises, improve the cognitive level of employees, and achieve the goal of matching the development speed of enterprises and employees.

(4) Considering the role of carbon emission trading in promoting TFEE, it is necessary to continue to speed up the construction of the carbon emissions trading market in pilot areas and improve the national unified carbon trading market system. When the government provides a good platform for trading subjects, it should also handle the relationship between the government and the market. Based on emphasizing fairness, scholars should give play to the role of the market mechanism, not interfere with the implementation of the carbon emission trading system, give play to the dominant position of enterprises in the market, use the market mechanism to guide the rational allocation of factors, save energy and improve energy utilization efficiency. To implement a carbon emission trading system, scholars should not only fully consider each region’s historical cumulative carbon emissions but also fully measure each region’s natural endowment and economic development to improve TFEE effectively. A differentiation strategy can be implemented.