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The Impact of New Quality Productive Forces on Carbon Emissions in Manufacturing Enterprises

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Abstract: The article innovatively explores new quality productive forces, focusing on their core role in driving carbon emissions. It investigates new quality productive forces' mechanisms and development pathways within the new economic environment. The paper delves deeper into the intrinsic connections between new quality productive forces and carbon emissions than existing research. Firstly, the paper investigates the impact and transmission mechanisms of China's new quality productive forces on green development. It calculates the carbon emissions of 2,364 manufacturing companies listed on the Shanghai and Shenzhen stock exchanges from 2011 to 2021. The study's empirical findings indicate that new quality productive forces promote carbon emissions reduction for publicly listed companies in the manufacturing sector. Lastly, the regression formula includes the number of patents listed companies hold. It is to consider the relationship between new quality productive forces and carbon emissions.

Keywords: New quality productive forces, Carbon emissions, Manufacturing.

1. Introduction

Green and sustainable development has become a global focal point in recent years. Since the reform and opening-up policy, China's economy has experienced rapid growth. However, its process has been accompanied by a high dependency on resources and environmental pollution issues. Green development is continuously being integrated into the national governance system. It is a widely discussed topic of improving ecological environment quality and promoting green economic growth.

New quality productive forces are emerging as a critical driving force for high-quality economic development. It is widely regarded as an essential comprehensive indicator of sustainable development. It emphasizes a win-win situation for economic prosperity and environmental governance. It reflects the allocation of resources, the technological level of production tools, changes in production goals, the efficiency of production organization and management, and workers' engagement in production activities. Additionally, it considers the impact of economic systems and various social factors on production activities. New quality productive forces incorporate digital and green economies into the productivity framework. It aligns with the concept of high-quality green development. Both aim to balance economic growth with environmental protection and are used to measure green development.

At the same time, as one of the largest carbon dioxide emitters, China faces climate change impacts that affect the sustainable development of human society. We are gradually making substantial progress toward carbon neutrality and peak carbon emissions. With the in-depth development of a new generation of communication and internet technologies, integrating productivity and digital technology has created a new form of productivity known as new quality productive forces. Its new form is rapidly emerging and profoundly transforming traditional productivity models. The combination of productivity and emerging information technologies is not merely a fusion of technology and productivity; it is a revolution that redefines productivity. Introducing new quality productive forces challenges traditional productivity and offers opportunities for innovation. New quality productive forces have a favorable impact on promoting economic growth and technological advancement. Therefore, can the rapid development of new quality productive forces effectively encourage carbon reduction and help achieve the dual carbon goals? If such an effect exists, what is the mechanism through which new quality productive forces impact carbon emission intensity? What role does innovation play in the relationship? Therefore, the paper will explore the abovementioned questions, aiming to contribute to advancing and achieving phased goals for low-carbon emission reduction.

They propose pathways for innovation development. The paper thoroughly assesses how new quality productive forces contribute to carbon emission reduction efforts by extensively reviewing existing literature and applying classic theories for analysis and guidance. We offer a new perspective for policy-making in carbon emissions and practical applications of new quality productive forces and suggest novel directions for future research. The paper enhances our understanding of the development paths linking new quality productive forces and carbon emissions by constructing a comprehensive theoretical framework. It offers new perspectives and ideas for policy-making, practical applications, and future research in carbon emissions. It also promotes the development of new quality productive forces in the new era.

Chapter 1 is the introduction. The chapter primarily analyzes the background and significance of the research and outlines the basic ideas, content, and innovation. Chapter 2 is the literature review, providing a detailed overview of the development status of new quality productive forces and carbon emissions. Chapter 3 presents theoretical hypotheses. Chapter 4 introduces variables and data, processing data from 2011 to 2021 for Shanghai and Shenzhen A-share listed manufacturing companies to calculate carbon intensity. The paper undergoes panel data tests such as the Hausman and robustness checks. It presents regression results from fixed effects models. Additionally, it discusses the mediating effects. Finally, Chapter 5 includes conclusions and recommendations.

The paper innovates in several aspects. Firstly, it explores the impact and mechanisms of new quality productive forces on carbon emissions. From the perspective of promoting innovation, the paper analyzes how new quality productive forces influence carbon emissions. It investigates the mechanisms through which new quality productive forces affect carbon emissions. Therefore, we can explore the primary channels through which new quality productive forces influence carbon emissions.

Moreover, it enriches the relevant theories on how new quality productive forces influence the development of the green economy. Secondly, new quality productive forces are still in the early stages. Little literature discusses its impact on carbon emissions, especially within the context of manufacturing companies listed on the Shanghai and Shenzhen stock exchanges. We examine the mechanisms by which new quality productive forces impact carbon emissions. It provides new evidence and helps broaden the research perspective on carbon emissions in the economy. Thirdly, despite the growing scholarly interest in the relationship between carbon emissions and new quality productive forces, there is limited research on how new productive forces affect carbon emissions. While many scholars have explored how new quality productive forces promote high-quality economic development, we analyze intermediary mechanisms from the perspective of innovation.

2. Literature References

2.1. New Quality Productive Forces

Productivity combines human labor with production resources (like land, machinery, etc.) during production. Productivity is the damn ability to create economic value and social wealth. The level of productivity directly impacts the quantity, quality, and efficiency of goods and services produced. Core elements of productivity include human resources, capital, technology, and management, with technology being considered the main driver of productivity improvement. Wang Wenhua et al. (2023) argue that the level of productivity development is an essential indicator of a country or region's economic development and social progress [1].

New quality productive forces are an essential part of driving economic development. It has become a core issue in China's economic transformation and upgrading. The government has attached great importance. Xi Jinping has emphasized on various occasions the importance of deepening reform of the science and technology system, accelerating the construction of an innovation-driven industrial system, cultivating new driving forces, and promoting high-quality development. Regarding the connotation and characteristics of new quality productive forces, Lu Minfeng and Ouyang Wenjie (2024) believe that new quality productive forces cover many aspects, such as innovation, industrial upgrading, and new business forms and models. It includes but is not limited to the development of high-tech industries, intelligent manufacturing, green energy, digital economy, and internet economy. It also contains innovation-driven development, prioritizing quality, advocating for green and low-carbon initiatives, and promoting openness and sharing [2]. Zhou Wen and Xu Lingyun believe that new quality productive forces are an essential innovation and development of Marxist productivity theory.

Additionally, they argue that the relationship between the market and the government must be considered, and an independent innovation system must be established to promote new quality productive forces. They also emphasize the need to strategically plan for emerging and future industries to enhance the focus on new quality productive forces [3]. Pu Qingping and Huang Yuanyuan have summarized the essential discussions on new quality productive forces from generative logic, theory, and contemporary value perspectives. They regard new quality productive forces as a result of the Sinicization of Marxism, pointing the way for high-quality development in China [4].

Table 1. The definition of the new quality productive forces.

Number	Perspectives	Author	Main content
1	Definition of productivity.	Wang Wenhua and Lu Minfeng	The level of productivity development is an essential indicator of a country or region's economic development and social progress.
2	Integration of the financial ecosystem with new quality productive forces.	Lu Minfeng and Ouyang Wenjie	New quality productivity includes various aspects such as technological innovation, industrial upgrading, and new business forms and models.
3	New quality productive forces can drive high-quality development.	Zhou Wen and Xu Lingyun	New quality productive forces are a breakthrough and innovation of Marxist productivity theory.
4	New quality productive forces are a high-quality productivity.	Pu Qingping and Huang Yuanyuan	New quality productive forces are another achievement of the sinicization of Marxism.

Scholars have proposed diverse insights on how to develop new quality productive forces. Zhang Yifan and Lu Minfeng (2024) emphasize the comprehensiveness of innovation. They pointed out that innovation requires technological progress and the support of institutions and the market environment [5]. Xu Mohan et al. (2024) approach from a global perspective. They emphasized that developing new, high-quality productive forces needs to be integrated into the global industrial chain, and resources and markets must be obtained through international cooperation [6]. New quality productive forces represent being driven by technological progress and innovation. Especially in emerging technological fields such as information technology, artificial intelligence, and big data, we can generate a new type of productivity that can lead the economy and society to a higher level of development. The core feature of productivity lies in the integration and application of technology. It dramatically improves production efficiency and innovation capabilities and promotes fundamental changes in production methods, economic structure, and even social organizational forms. The development of new quality productive forces relies on technology-driven approaches. Its characteristics are high efficiency, sustainability, intelligence, networking, and personalization. It marks a qualitative leap in productivity. It is an increase in quantity and a move towards quality improvement and upgrading. Some scholars believe the rise of such productivity is significant in promoting the transformation and upgrading of economic structure, improving social production efficiency and quality of life. It has also become the focus of competition among countries in the current and future periods and is a critical force in achieving sustainable development goals [7]. In addition, how new, quality, productive forces affect high-quality development has also continuously entered scholars' view. Different scholars have summarized the path of promoting high-quality development through new quality productive forces from the perspectives of advantageous conditions, innovative development, and the digital economy [8].

Table 2. The development path of new quality productive forces.

Number	Perspectives	Author	Main content
5	Technology finance plays the role of new quality productive forces	Zhang Yifan and Lu Minfeng	Developing new quality productive forces requires innovation
6	New quality productive forces drive the development of inclusive finance	Xu Mohan, Pei Xuan, and Lu Minfeng	Developing new quality productive forces requires integration into the global industrial chain.
7	New quality productive forces are the goal of becoming a financial powerhouse.	Lu Minfeng and Ouyang Wenjie	New quality productive forces promote the transformation and upgrading of economic structure to improve social production efficiency and quality of life.
8	New quality productive forces are an advanced form of productive forces	Xu Zheng, Zheng Linhao and Cheng Mengyao	New quality productive forces promote high-quality development

However, there is relatively little research on new quality productive forces in economics. Zhang Xiaheng and Ma Yan believe that new quality productive forces play a role in the digital economy. It adheres to independent technological innovation. Song Jia et al. used data from listed companies to study the impact of ESG on new quality productive forces in enterprises. They found that the development of ESG has a significant promoting effect on the new quality productive forces of enterprises, and the effect is more evident in private and small and medium-sized enterprises [10]. Zhu Fuxian and others used the Dagum Gini coefficient and Kernel density estimation methods to calculate the development level of new quality productive forces at China's regional level. They found that the development level of new quality productive forces is relatively high in the eastern region and relatively backward in the western and northeastern areas. From the above literature, it is not difficult to find that new quality productive forces have significantly impacted various aspects of politics and the economy [11].

Table 3. Digitalization empowers new quality productive forces.

Number	Perspectives	Author	Main content
9	New quality productive forces drive the digital economy.	Zhang Xiaheng and Ma Yan	New quality productive forces promote high-quality development of the digital economy.
10	The impact of ESG on new quality productive forces in enterprises	Song Jia, Zhang Jinchang, and Pan Yi	ESG has a significant promoting effect on new quality productive forces in enterprises
11	Calculating the development level of new quality productive forces in the region	Zhu Fuxian, Li Ruixue, and Xu Xiaoli	The development level of new quality productive forces is relatively high in the eastern region but relatively backward in the western and northeastern areas.

The similarity of the above studies is that new quality productive forces are closely related to improving economic efficiency and promoting social wealth creation. It emphasizes the crucial role of innovation and technological progress in promoting productivity improvement. Whether a general description of productivity or a specific focus on new quality productive forces, it reflects the key driving force for promoting economic and social development. The difference is that new quality productive forces particularly emphasize the impact of innovation on the qualitative leap of productivity and carbon emissions. In contrast, productivity emphasizes production capacity and its general role in the field of carbon emissions. The specific application of new quality productive forces in the carbon emissions field highlights technology's critical role in enterprises. It highlights the importance of technological progress and innovation for economic growth and social development.

2.2. New Quality Productive Forces and Carbon Emissions

New quality productive forces are a revolutionary leap in productivity quality. It is different from traditional productivity. Developing new quality productive forces helps to activate innovation, optimize industrial structure, and deepen factor supply. New quality productive forces can release green energy, provide transformation opportunities, and expand low-carbon paths to achieve carbon peak and neutrality. The digital economy belongs to new quality productive forces. It is an essential manifestation of productive force. Essentially, the digital economy represents advanced productive forces. It provides a solid foundation for the development of new quality productive forces. The core element of new quality productive forces is data, built on the foundation of the digital economy. The key to the development of new quality productive forces lies in technology. The focus of digital economy construction lies in innovation and progress. The economic increment it creates provides new demands for technological progress and revolution. It has driven the iterative updating and continuous leap of digital technology and technological means. It provides a broad platform for the development of new quality productive forces. Most existing literature studies the relationship and mechanism of carbon emissions from new quality productive forces. They believe a non-linear relationship exists between the digital economy and carbon emissions.

China is an essential producer of carbon dioxide. China has long been pressured to reduce carbon emissions while promoting economic and social growth. Wang Congqi and others have studied the relationship between the digital economy and carbon emissions. The impact of the digital economy on carbon emissions presents a non-linear inverted U-shaped relationship. Economic agglomeration plays a mediating role in the effects of the digital economy on carbon emissions. It can suppress carbon emissions. In addition, the impact of the digital economy on carbon emissions varies across different levels of development in various regions. Its main effect is concentrated in the eastern region, while its impact is weaker in the central and western areas. It indicates that its impact is mainly concentrated in developed regions [12].

Lei Xiaoying et al. believe that the carbon reduction effect of the digital economy is more substantial in provinces with higher economic levels. Energy structure and energy efficiency can indirectly affect carbon emissions. It has a mediating effect. The digital economy has an inverted U-shaped effect on the energy structure. It manifests as promoting first and then inhibiting, meaning negative first and then positive. It indicates a positive U-shaped impact on energy utilization efficiency. When the digital economy develops to a certain level, it can optimize energy structure and improve energy utilization efficiency. It can achieve the carbon reduction effect of the digital economy, and the reduction effect is significant [13]. Wang Haisen et al. conducted a comprehensive study on the direct and indirect impact of the digital economy on carbon emissions. The digital economy can reduce carbon emissions. It effectively curbs and reduces carbon emissions by strengthening low-carbon innovation and industrial diversification. However, there is a paradox in the digital economy. High levels of carbon emissions often accompany regions where the strength of the digital economy has improved. The high carbon emissions are a manifestation of digital industrialization. Digital industrialization will also hinder the carbon reduction efforts of the digital economy [14].

Table 4. The mediating effect of new quality productive forces on carbon emissions.

Number	Perspectives	Author	Main content
12	Non-linear inverted U-shaped relationship	Wang Congqi, Qi Fengyu, Liu Pengzhen, Haslindar Ibrahim and Wang Xiaoran	Economic agglomeration indirectly affects carbon emissions. Results show heterogeneity
13	Non-linear inverted U-shaped relationship	Lei Xiaoying, Ma Yifei, Ke Jinkai, and Zhang Caihong	Energy structure and energy utilization efficiency indirectly affect carbon emissions
14	Green technology innovation capability and industrial structure upgrading promote carbon reduction.	Wang Haisen, Yang Gangqiang, and Yue Ziyang	Directly affecting the reduction of carbon emissions, digital industrialization masks the inhibitory effect of the digital economy on carbon emissions.

The overall rapid development of the Chinese economy, however, there is a significant gap in development between cities. Therefore, the academic community has extensively explored the digital economy's carbon reduction mechanism from the perspective of cities. Wang Linzhu et al. analyzed its transmission mechanism, spatial spillover effects, and spatiotemporal heterogeneity. The digital economy significantly impacts carbon emission intensity, and its development helps achieve carbon reduction targets. The digital economy can promote carbon dioxide reduction by encouraging innovation in green technology and upgrading industrial structures. However, a significant impact exists in specific regions, and there is no spillover effect on carbon reduction from the digital economy in surrounding areas. In addition, there are differences in the impact of digital economy development on carbon emissions in different regions and stages of development [15]. Meng Ziyu et al.'s research indicates that the digital economy has been essential in promoting carbon reduction in Chinese cities. The digital economy has reduced urban carbon emissions through two channels. One is to promote the upgrading of urban industrial structures, and the other is to enhance the green innovation capacity of cities.

Over time, the promoting effect of the digital economy on urban carbon reduction will gradually become apparent. However, there is heterogeneity in the impact of the digital economy on urban carbon reduction. It indicates a significant positive impact on carbon reduction in cities in eastern China, while the promoting effect on central and western China cities is not very substantial [16]. Ma Lindong et al. studied the digital economy's impact mechanism and spatial effects on carbon emission intensity in cities along the Yangtze River Economic Belt. Their research indicates that the development of the digital economy can significantly reduce the carbon emission intensity of cities in the Yangtze River Economic Belt. Its effect is mainly achieved through two pathways. One is to promote rationalizing and upgrading industrial structures, and the other is to enhance green innovation in cities.

The development of the digital economy has a spillover effect on the carbon emission intensity of surrounding cities. In contrast, it has a suppressive effect on the carbon emission intensity of neighboring cities. In addition, there is significant spatial heterogeneity in the impact of the digital economy, especially in the downstream areas of cities in the Yangtze River Economic Belt. The development of the digital economy has a significant inhibitory effect on carbon emissions [17]. Cui Huanyu et al.'s research indicates that the digital economy significantly impacts total factor carbon productivity. And it generates spatial spillover effects. The digital economy has dramatically improved total factor carbon productivity. Especially compared to industrial digitization, digital industrialization has a more positive impact on total factor carbon productivity. The scale of the digital economy, human capital, market segmentation, and resource mismatch are mediators that affect the total factor of carbon productivity. The development of the digital economy scale is the most crucial intermediary path. The development of the digital economy not only promotes the improvement of local total factor carbon productivity but has a positive spatial spillover effect on the total factor carbon productivity of surrounding areas. Spatial heterogeneity analysis reveals that the northern region can benefit more from developing the digital economy [18]. Luan Bingjiang et al. used a lifecycle assessment model to study the impact and underlying mechanisms of the digital economy on carbon transfer between Chinese cities. Research has found that carbon transfer is a common phenomenon among Chinese cities. The digital economy has facilitated the transfer process. The digital economy indirectly affects carbon transfer between cities by promoting market integration and industrial transfer. The study also found that the more developed the local cities are, the more significant the promoting effect of the digital economy on carbon transfer. It is mainly reflected in promoting the transfer of carbon emissions from the secondary industry in developed cities to underdeveloped cities. In addition, implementing mandatory environmental regulations further amplifies the role of the digital economy in promoting carbon transfer. It exacerbates the positive impact of the digital economy on carbon transfer [19].

Table 5. The impact mechanism of new quality productive forces on carbon emissions at the urban level.

Number	Perspectives	Author	Main content
15	Promoting urban carbon reduction	Wang Linzhu, Sun Yixin, and Xv Deyi	The impact on carbon emissions is non-linear. Green technology innovation and industrial structure upgrading indirectly reduce carbon dioxide emissions. The spatial spillover effect of its impact is insignificant, and there is spatiotemporal heterogeneity.
16	Suppressing urban carbon emissions	Meng Ziyu, Li WenBo, Chen Chaofan and Guan Chenghua	The upgrading of urban industrial structures and the green innovation capacity of cities indirectly affect carbon emissions. Its impact exhibits temporal and spatial heterogeneity.
17	Suppressing carbon emissions in cities along the Yangtze River Economic Belt	Ma Lindong, Hong Yuanxiao, He Shouchao, He HaibeiX, Liu Guangming, Zheng Jinhui, Xia Yuntian and Xiao Deheng	The intermediary effect of industrial structure optimization, upgrading, and green technology innovation reduces carbon emission intensity. Its impact has positive spatial spillover effects and spatial heterogeneity.
18	Reducing total factor carbon productivity	Cui Huanyu, Cao Yuequn and Zhang Chi	The digital upgrading of industries and human capital accumulation indirectly affect the total factor of carbon productivity. Its impact has positive spatial spillover effects and spatial heterogeneity.
19	Promoting carbon transfer between cities	Luan Bingjiang, Yang Hanshuo, Zou Hong and Xi Yu	Market integration and industrial transfer indirectly promote carbon transfer between cities. There is heterogeneity in its impact. The transfer of carbon emissions has a significant effect on developed cities.

Scholars at home and abroad have extensively discussed carbon emission rates. Many scholars have confirmed the role of new quality productive forces in carbon emissions from theoretical and empirical perspectives. They also explored its mechanism of action and analyzed how to reduce carbon emissions. In addition, new, high-quality, productive forces are rapidly developing in China. Many scholars have begun considering the relationship between new quality productive forces and the green economy.

3. Overview of New Quality Productive Forces and Carbon Emissions

3.1. Development of New Quality Productive Forces in China

The concept of new quality productive forces was first proposed in the 1980s in Shi Zheng's on the Decisive Role of Geographical Environment in Early Social Development, originally used to describe a new form of productivity. It has essential differences from traditional productive forces [20]. At that time, new quality productive forces mainly referred to the productivity improvement brought about by information technology. It includes the application of computers, the Internet, and other emerging technologies. With the continuous progress of technology, new technologies are constantly emerging. It provides strong support for the improvement of productivity. From information technology to artificial intelligence and then to biotechnology and new material technology, every innovation has opened up new space for developing new quality productive forces.

Developing new quality productive forces is an inevitable product of productivity development to a particular stage. It is also a manifestation of a change in approach. Deng Xiaoping pointed out that science and technology are the primary productive forces. The leap in productivity is a process from quantitative change to qualitative change. When key technologies achieve breakthroughs and undergo qualitative changes, they inevitably transform the core productivity factors, resulting in new quality productive forces. In 2023, Xi Jinping first proposed the integration of innovation resources during his inspection in Heilongjiang. It leads the development of strategic emerging and future industries, accelerating the formation of new quality productive forces. New quality productive forces are led by innovation. It is also the productivity generated by achieving key disruptive technological breakthroughs. New quality productive forces emphasize breakthroughs and creative combinations of traditional production factors. It can form a new system of elements. New quality productive forces emphasize coordination and optimization among various elements to enhance efficiency.

Productivity is the prerequisite and foundation for the formation of production relations. Production relations are established to meet the requirements for developing productive forces. It is the development form of productivity. Its nature must adapt to the conditions of productivity. It is compatible with the formation of new quality productive forces. We need to accelerate the transformation of institutional mechanisms driven by innovation. Continuously adjusting production relations can stimulate the vitality of social productivity development. The proposal of new quality productive forces is the development and innovation of Marxist productivity theory. It is also the sinicization and modernization of Marxist political economy. The key to new quality productive forces is novelty and quality. New refers to productivity that is different from traditional productivity. Productivity is a productive force with new technology, economy, and business models as its primary connotations. Quality emphasizes innovation as an essential element of productivity. It will achieve critical technological breakthroughs in productivity for self-reliance and self-improvement. Therefore, new quality productive forests are productivity-driven by innovation. It has the characteristics of high efficiency and high quality. It differs from the traditional mode of productivity development, which relies on a large amount of resource input and high consumption. It breaks away from conventional growth paths. It meets the requirements of high-quality development. The digital age is more integrated and reflects new connotations of productivity.

Economic development cannot do without breakthroughs in science and technology. Every breakthrough in science and technology drives the gradual disintegration of the old productivity system. It is the driving force behind the gradual formation of the new quality productive forces system. A new technological revolution and industrial transformation are deepening. The world has entered an era of highly concentrated innovation. China's economic development has faced complex internal and external environments in recent years. Whether it is boosting confidence, promoting economic recovery, or occupying a strategic initiative in future growth and international competition. Innovation is crucial. The focus is on breakthroughs in critical and disruptive technologies. The proposal of new quality productive forces indicates that innovation drives industrial upgrading. It can build new competitive advantages and gain development initiatives.

3.2. Development of Carbon Emissions

In the current process of socio-economic development. The production and operation of any industry cannot be separated from the consumption of coal, oil, etc. At the same time, the regional economic level is improving, and the population is increasing further. The consumption of resources and gas emissions are also showing a growing trend. It leads to various issues, such as the greenhouse effect. It not only breaks the balance of coexistence between humans and nature. And it directly damages the human living environment. With the increasing attention paid to the environmental impact of carbon emissions, the issue of carbon emissions is receiving more widespread attention. Carbon emissions refer to the emission of greenhouse gases such as carbon dioxide generated by human activities into the atmosphere. It leads to the process of global climate change. China is one of the world's largest greenhouse gas emitting countries, and its carbon emissions have always been high. The dual carbon target will become a key focus of China's future development. The overall carbon emissions level in China is shown in Table 6, and the country's carbon emissions have continued to increase from 2000 to 2013. From 2014 to 2016, China's carbon emissions showed a slow downward trend. However, after 2016, China's carbon emissions have shown a sluggish growth trend. In recent years, global climate change has become increasingly severe. A low-carbon economy has become the primary trend in developing various countries. China is also actively promoting the work of peaking carbon emissions and achieving carbon neutrality. We aim to achieve a win-win situation between economic development and environmental protection.

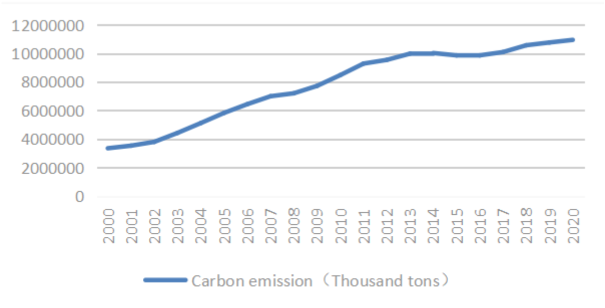

Figure 1. The overall carbon emissions level in China from 2000 to 2020

4. Theoretical Mechanisms and Research Hypotheses

Productivity is a broad concept. It encompasses the ability to create value in all industries and fields. And new quality productive forces are a subset of productivity. It focuses on developing new productive forces at a higher level driven by technological progress and innovation. New quality productive forces represent a new mode of production and development. It emphasizes the core position of innovation and the pursuit of higher quality and efficiency. It also emphasizes sustainable development and open cooperation. In the global economic landscape context, the cultivation and development of new, quality, productive forces are of great strategic significance for any country or region.

Zhang Xiu'e and others believe that new, high-quality productive forces are a strong driving force and support for the high-quality development of enterprises. They studied and explored using new quality productive forces to drive enterprise development. They empirically analyzed the impact of digital transformation and the heterogeneity of its characteristics on enterprises' new quality productive forces. They found that digital transformation significantly impacts the improvement of new quality productive forces in enterprises. The absorptive capacity of enterprises plays a mediator role between digital transformation and new quality productive forces. The intensity of market competition plays a positive regulatory role in the relationship between digital transformation and new quality productive forces [21]. Yuan Hankun and Xu Zheng studied the impact of new quality productive forces on the resilience of industrial and supply chains. They found that new quality productive forces can improve the strength of industrial and supply chains [22].

Although current research suggests that developing new quality productive forces may impact energy consumption and carbon emissions, relatively little literature directly explores the relationship between new quality productive forces and carbon emissions. The mechanisms involved have not yet been systematically explained. A detailed analysis of the theoretical mechanism of the impact of new quality productive forces on carbon emissions is an important direction for future research. Based on these elements, the following assumptions are proposed.

Hypothesis 1: New quality productive forces can significantly reduce corporate carbon emissions levels.

New quality productive forces may affect a company's carbon emissions through innovation. The popularization and application of technology have a significant impact on innovation efficiency. Improvements in innovation can promote the development of green and environmentally friendly technologies. Using environmentally friendly materials, recycling technology, and pollution control equipment can enhance a company's ability to monitor carbon emissions. In addition, improving the level of innovation helps promote the market popularization of green technology and increases the market demand for green technology. It encourages the development of high-tech industries. The continuous transformation and upgrading of industrial structures can gradually eliminate enterprises with high energy consumption and pollution. However, in the past, few studies have discussed the mediator role of innovation. Based on these factors, the following assumptions are proposed.

Hypothesis 2: Innovation mediates the relationship between new quality productive forces and corporate solid carbon emissions.

Table 6. New quality productive forces and green economy.

Number	Perspectives	Author	Main content
21	Digitalization promotes new quality productive forces in enterprises	Zhang Xiu'e, Wang Wei, and Yu Yongbo	The absorption capacity plays a mediating role. Positive regulatory effect of market competition intensity
22	New quality productive forces promote the resilience improvement of industrial and supply chains	Yuan Hankun and Xu Zheng	There is heterogeneity in its impact effect

5. Analytical Framework

5.1. Data Sources

Considering the large sample size and long-lasting time of listed companies in the industrial industry, the corresponding annual reports contain richer and more complete data. We selected Shanghai and Shenzhen A-share-listed manufacturing enterprises in 2011-2021 as the research objectives. We also carry out the following steps of data filtering. (1) Exclude enterprise samples from ST, ST*, and PT. (2) Exclude listed companies with missing values of relevant variables. (3) Due to the availability of data in Xizang, the sample of enterprises with offices in Xizang is excluded. Finally, the research object is determined to include 29 industries and 2364 enterprises. It has a total of 14861 observation samples for one year of enterprises. The raw data used at the enterprise level of the research institute mainly comes from CSMAR and CNRDS databases. In contrast, industry-level data comes from the China Industrial Statistical Yearbook and China Energy Statistical Yearbook.

5.2. Indicator Descriptions

5.2.1. Measurements of New Quality Productive Forces

The dependent variable is the enterprise's new quality productive forces. The core of new quality productive forces is innovation. It is based on the theory of two factors of productivity [23] and considers the role and value of labor objects in the production process. We use the entropy method to measure new quality productive forces. The data is sourced from the Wind database. We draw on the research methods of Song Jia et al. [10]. The specific methods are as follows.

Table 7. Indicators of new quality productive forces.

	Primary indicators	Secondary indicators	Indicator Description	Weight
Labor force	Live labor	The proportion of R&D personnel' salary	R&D expenses, salaries, and salaries/operating income	26
		Proportion of R&D personnel	Number of R&D personnel/number of employees	2
		The proportion of highly educated personnel	(Master+Doctor)/number of employees	3
	Materialized labor	Proportion of fixed assets	Fixed assets/total assets	1
		Proportion of manufacturing cost	(Cash outflows from operating activities+depreciation of fixed assets+amortization of intangible assets+asset impairment - cash paid for purchasing goods and receiving services - wages paid to and for employees)/(Cash outflows from operating activities+depreciation of fixed assets+amortization of intangible assets+asset impairment)	1
Production tools	Hard technology	The proportion of direct depreciation and amortization in R&D'expenses	Direct depreciation and amortization in expenses/operating income	24
		Proportion of leasing expenses in R&D'expenses	Leasing expenses in expenses/operating income	13
		Proportion of direct investment in R&D'expenses	Direct investment in expenses/operating income	27
		Proportion of intangible assets	Intangible assets/total assets	1
	Soft technology	Total asset turnover rate	Operating income/[(total assets of the current year+total assets of the previous year)/2]	1
		Reciprocal of the equity multiplier	Owner's equity/total assets	1
New quality productive forces				100

The first step is to select strategic emerging and future industries closely related to new quality productive forces. They are used as samples to calculate new quality productive forces. The second step is to construct a new quality productive forces indicator system based on the theory of two factors of productivity [23]. Productivity includes labor and production tools. The labor force comprises live labor and materialized labor, and production tools are composed of hard and soft technology. The sub-factor indicators of live labor include the proportion of R&D personnel salaries, R&D personnel, and highly educated personnel. The sub-factor indicators of materialized labor include the proportion of fixed assets and manufacturing costs to measure. The sub-factor indicators of complex technology are calculated by the proportion of direct depreciation and amortization in R&D expenses, leasing expenses in R&D expenses, direct investment in R&D expenses, and intangible assets. The sub-factor indicators of soft technology are represented by total asset turnover and the reciprocal of equity multiplier. The values of the above indicators are explained in Table 7. The third step is to use the entropy method to calculate each indicator's weights, forming the enterprise's new quality productive forces indicator [10].

5.2.2. Measurement of Carbon Intensity

The explanatory variable is corporate carbon intensity. When evaluating the carbon emission levels of enterprises, it was found that few companies voluntarily disclose carbon emission data in their annual reports. Due to the limited availability of microdata for enterprises, we draw on the research method of Shen Hongtao et al. [24]. Industry energy consumption can approximate the carbon dioxide emissions of enterprises. The specific calculation method can be found in Equation 1-3. The operating costs and revenue of enterprises (in billions of yuan) are sourced from the Guotai An database. The main operating costs of the industry (in billions of yuan) and the total energy consumption of the industry (in tens of thousands of tons) are sourced from the China Industrial Statistical Yearbook and the China Energy Statistical Yearbook, respectively. According to the carbon dioxide calculation standard of the Xiamen Energy Conservation Center, the carbon dioxide conversion coefficient for 1 ton of standard coal is 2.493. Multiplying by 10000 is the total energy consumption of the industry, measured in 10000 tons. To reduce the volatility of the data, natural logarithmic processing is applied to the carbon emission intensity.

$$\text{Carbon dioxide emissions} = \frac{\text{Operating costs}}{\text{Main operating costs}} \times \text{total energy consumption of the industry} \times \text{carbon dioxide conversion coefficient} \times 10000 \quad (1)$$

$$\text{Carbon intensity} = \text{Carbon dioxide emissions}/\text{Operating income} \quad (2)$$

$$\text{The logarithm of carbon emission intensity} = \ln(1 + \text{Carbon intensity}) \quad (3)$$

5.2.3. Selection of Mechanism Variables

The control variables include CAP, Lev, ROE, FIXED, Cashflow, ListAge, and ROA. The mediator variable is innovation. The meanings and calculations of each variable are shown in Table 8.

Table 8. Definition of variables.

Variable	Variable symbols	Variable name	Variable measurement
Dependent variable	New Quality Productive Forces	New quality productive forces	Entropy weight of labor and production tools
Independent variable	Carbon Intensity	Carbon emission intensity of enterprises	Carbon dioxide emissions of enterprises/operating income of enterprises
Control variable	CAP	Capital intensity	Total assets/operating income
	Lev	Debt to assets ratio	Total liabilities at the end of the year/total assets at the end of the year
	ROE	Return on equity	Net profit/average balance of owner's equity
	FIXED	Proportion of fixed assets	Net fixed assets/total assets
	Cashflow	Cash flow ratio	Net cash flow generated from operating activities/total assets
	ListAge	List age	Ln (this year- year of listing+1)
	ROA	Return on assets	Net profit/average balance of total assets
	Industry	Industry effects	Industry dummy variable
	Year	time effect	Year dummy variable
Mediator variable	Innovate	Innovation	The natural logarithm of the number of patent applications plus 1

5.3. Model Design

The study's dependent variable is carbon emission intensity, and the key independent variable is new quality productive forces. The purpose is to study the relationship between these two variables. We introduce a series of control variables to regulate the impact of macroeconomic factors. To verify hypothesis 1, the article constructs a model as follows.

$$\text{Carbon Intensity}_{i,t} = \alpha_0 + \alpha_1 \text{New Quality Productive Forces}_{i,t} + \sum \alpha_k \text{Controls}_{it} + \varphi_i + \pi_t + \varepsilon_{it} \quad (4)$$

In the model, the subscript i represents the enterprise, and t represents the year. Carbon Intensity represents the dependent variable. New Quality Productive Forces represent the core variables explained. Controls represent a series of control variables. φ_i represents industry fixed effect and π_t Represents time-fixed effects. α_0 represents the intercept term. ε_{it} Represents a random disturbance term that varies with industry and time. α_1 and α_k are coefficients for New Quality Productive Forces and Controls. The empirical model used is a bidirectional fixed effects model. It can alleviate endogeneity problems caused by factors such as missing variables.

The mediating effect is the indirect influence of the independent variable on the dependent variable through the intermediate variable. It is to test whether innovation factors can play a mediating role as variables. We conducted further empirical research using the three-step method of the mediation effect model [25]. Specifically, to verify hypothesis 2, the independent variable (X) has an indirect impact on the dependent variable (Y) through the intermediate variable (M). Detailed steps can be found in equations 4-6.

$$\text{Innovate}_{i,t} = \alpha_0 + \alpha_1 \text{New Quality Productive Forces}_{i,t} + \sum \alpha_k \text{Controls}_{it} + \varphi_i + \pi_t + \varepsilon_{it} \quad (5)$$

$$\text{Carbon Intensity}_{i,t} = \alpha_0 + \alpha_1 \text{New Quality Productive Forces}_{i,t} + \alpha_2 \text{Innovate}_{i,t} + \sum \alpha_k \text{Controls}_{it} + \varphi_i + \pi_t + \varepsilon_{it} \quad (6)$$

Carbon Intensity is the dependent variable Y. Innovation is the mediate variable M to be tested. New Quality Productive Forces is a mediate effect model constructed using the independent variable X.

5.4. Results

5.4.1. Descriptive Statistics

The descriptive statistical results of the main variables are detailed in Table 9. The maximum logarithmic value of carbon emission intensity is 10.450, and the minimum is 0.708. There is a significant gap in the carbon emission intensity of Chinese enterprises, and the average logarithm of carbon emission intensity is greater than the median. Most enterprises have high levels of carbon emission intensity. The maximum value of new quality productive forces is 0.028, and the minimum is 0. It indicates a small gap in new quality productive forces among Chinese enterprises. The average of new quality productive forces is 0.005, equal to the median 0.005. More than half of the companies have new quality productive forces below average. Currently, Chinese enterprises need to improve their new quality productive forces further.

Table 9. Statistical description of the variables.

Variable	Observation	Mean	SD	Minimum	Median	Maximum
The logarithm of carbon emission intensity	14861	7.820	1.128	0.708	7.452	10.450
New quality productive forces	14861	0.005	0.002	0.000	0.005	0.028
CAP	14861	2.025	1.509	0.378	1.679	18.942
Lev	14861	0.417	0.191	0.032	0.411	0.908
ROE	14861	0.065	0.127	-0.926	0.068	0.419
FIXED	14861	0.240	0.139	0.002	0.216	0.719
Cashflow	14861	0.050	0.067	-0.199	0.048	0.257
ListAge	14861	2.210	0.774	0.000	2.398	3.367
ROA	14861	0.043	0.063	-0.373	0.039	0.247

5.4.2. Hausman Test

Table 10. Hausman test results.

	(1)	(2)
	Random effect	Fixed effect
	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity
New quality productive forces	-18.83***	-14.34***
	(-7.73)	(-5.81)
CAP	-0.0273***	-0.0263***
	(-9.88)	(-9.56)
Lev	0.125***	0.108***
	(4.49)	(3.88)
ROE	0.158**	0.162**
	(2.98)	(3.08)
FIXED	0.517***	0.339***
	(12.72)	(8.23)
Cashflow	-0.198***	-0.185***
	(-4.03)	(-3.81)
ListAge	0.0170*	0.00340
	(2.35)	(0.46)
ROA	-1.151***	-1.203***
	(-9.23)	(-9.75)
Consant	7.786***	7.859***
	(262.13)	(367.20)
Prob> chi2	0.0000	
chi2 (8)	1543.9	

The standard errors are in parentheses, and asterisks*, **, *** show the significance level at 10, 5, and 1 percent.

Hausman (1978) believes that if the sample is randomly selected from the total sample, then the effect term of each sample is a random variable. If these samples are not randomly chosen from all, evaluate the differences between these samples. The fixed effects model is more suitable [26]. Data processing selected panel data from 2364 companies with continuous 10-year statistics. The selection of panel data models can be tested using the Hausman test. The Hausman test results show a p-value of 0.00000. Due to the low significance (0.05), the null hypothesis was rejected. Fixed effects are superior to random impacts. A fixed effects model should be used instead of a random effects model. We select fixed effects models for years and industries.

5.4.3. Basic Regression

Table 11 shows the benchmark regression results. Column (1) shows the direct regression results between the independent and dependent variables when controlling for time and industry-fixed effects. Columns (2) - (8) show the regression results of adding control variables in sequence when controlling for time and industry-fixed effects. Before and after adding control variables, the coefficient of new quality productive forces is significantly negative at 1%. New quality productive forces can dramatically reduce the carbon emissions level of enterprises. Hypothesis 1 is true.

Table 11. Benchmark regression result.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity
New quality productive forces	-0.282	-0.657	-3.209***	-4.070***	-9.441***	-8.663***	-9.301***	-8.725***
	(-0.25)	(-0.59)	(-3.00)	(-3.93)	(-8.39)	(-7.82)	(-8.42)	(-8.05)
CAP		-0.016***	-0.012***	-0.024***	-0.023***	-0.027***	-0.028***	-0.031***
		(-11.39)	(-8.77)	(-16.84)	(-16.18)	(-19.66)	(-20.26)	(-22.48)
Lev			0.378***	0.289***	0.280***	0.248***	0.205***	0.114***
			(33.67)	(25.76)	(25.01)	(22.37)	(17.59)	(9.46)
ROE				-0.530***	-0.505***	-0.374***	-0.367***	0.408***
				(-31.60)	(-29.97)	(-21.25)	(-20.93)	(11.25)
FIXED					0.213***	0.283***	0.284***	0.228***
					(11.91)	(15.79)	(15.94)	(12.92)
Cashflow						-0.735***	-0.741***	-0.507***
						(-21.74)	(-22.01)	(-14.75)
ListAge							0.033***	0.025***
							(11.73)	(9.04)
ROA								-1.963***
								(-24.28)
Consant	7.821***	7.857***	7.703***	7.801***	7.776***	7.807***	7.758***	7.850***
	(1350.60)	(1200.67)	(989.14)	(956.26)	(927.24)	(931.92)	(829.09)	(789.84)
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	14861	14861	14861	14861	14861	14861	14861	14861
R2	0.947	0.948	0.951	0.954	0.955	0.956	0.957	0.958
Adj. R2	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.96

The standard errors are in parentheses, and asterisks*, **, *** show the significance level at 10, 5, and 1 percent.

5.4.4. Robustness Test

To make the empirical results more robust, two methods are used to test the robustness of the empirical results. The first is to replace the dependent variable. The changes in carbon emission intensity of listed companies have a particular lag characteristic. The lagged y period replaces the dependent variable to verify the medium to long-term changes in the impact of new quality productive forces on the carbon emission intensity of manufacturing enterprises. The regression results are shown in column (1) of Table 12. The coefficient of new quality productive forces is still significantly negative, and the significance has improved. The results have become better. The second is to remove samples. Some municipalities directly under the central government have exceptional green policy support, and there is a gap in the level of urban development. To avoid observation errors caused by uncontrollable factors, the sample of enterprises in municipalities directly under the central government is excluded. Enterprises in ordinary cities are undergoing a diversified regression. Column (2) displays the regression results. The effect of new quality productive forces on the carbon emission intensity of manufacturing enterprises remains significantly negative. Although the significance has decreased, there has been no substantial change in the results. After using the above robustness testing method, all empirical results are consistent with the benchmark regression results. A series of regression results indicate that the conclusion is robust.

Table 12. Robustness checks.

	Replace dependent variable	Reduce sample size
	(1)	(2)
	L. Logarithmic of carbon emission intensity	Logarithmic of carbon emission intensity
New quality productive forces	-9.144***	-8.403***
	(-6.34)	(-6.99)
CAP	-0.026***	-0.029***
	(-14.14)	(-20.77)
Lev	0.151***	0.110***
	(9.25)	(8.90)
ROE	0.412***	0.408***
	(8.04)	(10.90)
FIXED	0.264***	0.216***
	(11.11)	(11.67)
Cashflow	-0.425***	-0.502***
	(-8.99)	(-14.28)
ListAge	0.041***	0.021***
	(9.52)	(7.35)
ROA	-1.487***	-1.974***
	(-13.15)	(-23.75)
constant	7.755***	7.878***
	(531.91)	(774.33)
Industry	Yes	Yes
Year	Yes	Yes
N	12509	13924
R2	0.936	0.959
Adj. R2	0.94	0.96

The standard errors are in parentheses, and asterisks*, **, *** show the significance level at 10, 5, and 1 percent.

5.4.5. Mediating Effect Model Regression

Table 13. Mediating effect regression result.

	(1)	(2)	(3)
	Logarithmic of carbon emission intensity	Patent	Logarithmic of carbon emission intensity
New quality productive forces	-8.725***	75.49***	-8.220***
	(-8.05)	(11.16)	(-7.56)
CAP	-0.0308***	-0.0886***	-0.0313***
	(-22.48)	(-10.38)	(-22.85)
Lev	0.114***	1.005***	0.121***
	(9.46)	(13.37)	(9.97)
ROE	0.408***	-0.147	0.407***
	(11.25)	(-0.65)	(11.23)
FIXED	0.228***	-0.513***	0.225***
	(12.92)	(-4.65)	(12.73)
Cashflow	-0.507***	1.504***	-0.497***
	(-14.75)	(7.01)	(-14.45)
ListAge	0.0248***	-0.241***	0.0232***
	(9.04)	(-14.10)	(8.41)
ROA	-1.963***	2.459***	-1.946***
	(-24.28)	(4.87)	(-24.08)
patent			-0.00669***
			(-5.08)
Constant	7.850***	1.708***	7.862***
	(789.84)	(27.54)	(772.13)
N	14861	14861	14861
R2	0.958	0.188	0.958
adj. R2	0.958	0.185	0.958
		Coef	p
Sobel test	Indirect effect	-.504786	3.7e-06
	Direct effect	-8.21991	3.9e-14
	Total effect	-8.7247	8.9e-16
	Proportion of total effect	.0578571	
		Confidence interval	
Bootstrap test	Indirect effect	-.726348	-.3333525
	Direct effect	-11.15795	-6.017311
	Total effect	-11.7142	-6.520091

The standard errors are in parentheses, and asterisks*, **, *** show the significance level at 10, 5, and 1 percent.

The level of enterprise innovation is measured to test the mediating effect of innovation. The number of patents in a company reflects its level of innovation. Table 13 presents the results of the mediating effect test for innovation. In column (2), the estimated coefficient of new quality productive forces is significantly positive at the 1% level. The level of technological innovation in enterprises can substantially promote the development of new quality productive forces. The estimation coefficient of the logarithm of carbon emission intensity for new quality productive forces in column (3) is significantly negative at the 1% level, and the P-value of the Sobel test is less than 0.05. The mediating effect exists, and the bootstrap test statistic also passes the significance test. Indirect effects (bs1) do not include significant indirect effects, and the mediating effect does exist. The direct effect (bs2) does not include 0, indicating the existence of direct effects and partial mediating effects. The above analysis results suggest that innovation mediates the process of new quality productive forces affecting corporate carbon emissions. In other words, new quality productive forces enhance technological innovation to suppress carbon emissions. Hypothesis 2 is accepted.

6. Conclusion

China is currently in a critical period of transformation. Climate governance has become a significant development issue for China. In the process of achieving carbon peak and carbon neutrality goals in a safe and orderly manner, new quality productive forces have played a significant role. For this reason, we collected data on Shanghai and Shenzhen A-share listed manufacturing enterprises from 2011 to 2021. We construct a comprehensive index system for new quality productive forces and measure carbon emission intensity. We empirically analyze the impact of developing new quality productive forces on the carbon emission intensity of manufacturing enterprises. It also revealed the inhibitory effect and underlying mechanism of new quality productive forces empowering carbon emissions. We test the mediating role of innovation. The main conclusions are as follows. (1) Developing new quality productive forces significantly reduces the carbon emission intensity of enterprises. Its result remains after a series of robustness tests, such as replacing the dependent variable and adjusting the study sample. (2) The intermediary mechanism test shows that new quality productive forces suppress the carbon emission intensity of enterprises by improving their innovation level.

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