The Dual Effects of the Carbon Pricing Mechanism: A Balanced Path between Economic Costs and Environmental Benefits

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Abstract. Global climate governance increasingly relies on carbon pricing mechanisms to achieve emission reduction targets. As of 2024, 75 carbon pricing policies have been implemented globally, covering 24% of greenhouse gas emissions. As the largest carbon emitter, China launched its national carbon market in 2021 but still faces the challenge of balancing economic growth and low-carbon transformation. This study systematically assesses the economic and environmental effects of carbon pricing mechanisms (carbon taxes, carbon trading systems, and hybrid models) by comparing international practices (such as the EU carbon market and the Canadian carbon tax) with China's policy framework. Hybrid mechanisms (such as the connection between China's pilot markets and the national carbon market) can enhance policy flexibility and reduce the compliance costs of emission control enterprises. At the same time, it encourages technological innovation, such as hydrogen energy steelmaking projects. Finally, long-term decarbonization relies on technological transformation and policy coordination, such as the combination of the EU carbon market and renewable energy subsidies, to promote the average annual stable growth of wind power installed capacity. The research emphasizes the necessity of differentiated policy design (such as free quota allocation and carbon tax rebates). The above conclusion provides a feasible path for optimizing China's carbon pricing framework and coordinating the "dual carbon" goals, highlighting the importance of cross-departmental policy coordination and risk adjustment carbon pricing mechanisms.

Keywords: Carbon Pricing Economic Effect, Environmental Effect, Policy synergy Carbon neutrality.

1 Introduction

Global climate change governance is accelerating its shift towards market-based tools, and carbon pricing mechanisms (carbon taxes, carbon trading, and hybrid models) have become core policies for achieving the carbon neutrality goal. As of 2024, 75 countries and regions around the world have implemented carbon pricing tools, covering 24% of greenhouse gas emissions [1]. The EU Emissions Trading System (EU ETS), as a benchmark case, saw its carbon price exceed 100 euros per ton in 2023, driving the

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power industry to reduce emissions by 43% compared to 2005 [3], while the Canadian federal carbon tax forced the transformation of household energy consumption through a 10% increase in gasoline prices [2]. China launched its national carbon market in 2021, with an annual transaction volume exceeding 10 billion yuan. However, issues such as insufficient connection between the pilot program and the national market and limited incentives for enterprises to reduce emissions still restrict the effectiveness of the policy [3].

Existing studies have significant differences in the economic and environmental effects of carbon pricing. In terms of economic effects, relevant scholars Some scholars verified the reconstructing effect of carbon prices on enterprise production decisions based on machine learning methods and found that the internalization of carbon costs significantly promotes technological upgrading in energy-intensive industries [2]. However, other scholars pointed out that a single carbon pricing may lead to the risk of industrial chain transfer. For instance, the German cement industry moved to Eastern Europe to avoid costs [4]. At the environmental impact level, some scholars have found that carbon prices achieve differentiated emission reduction paths through short-term technological improvements (such as energy efficiency enhancements) and long-term structural transformations (such as hydrogen steelmaking) [4]. Some scholars emphasized the key role of policy synergy (such as the linkage between the carbon market and green certificate trading) in reducing the cost of emission reduction [5]. It is worth noting that Chinese scholar demonstrated through a dynamic CGE model that the synergy of carbon pricing and innovation input can reduce GDP losses by 1.2% and drive the technological progress rate of renewable energy to an average of 3.5% per year. [3]

The current research gaps are concentrated in three aspects. First, there is a lack of systematic comparison in the design of differentiated mechanisms between international experience and Chinese practice. For example, the path and method of reducing carbon intensity by 20% through the utilization of 30% scrap steel in the Turkish steel industry has not been valued and learned and has not been incorporated into the mainstream analytical framework. Secondly, the influence of carbon pricing on the behavior of micro-subjects has not yet been clarified. Some scholars found based on French manufacturing data that EU ETS prompted enterprises to invest in clean technologies, reducing marginal costs by 8%, but failed to explain the industry heterogeneity of technology diffusion [3]. Thirdly, the quantification of policy synergy effects is insufficient. Some scholars proposed the classification of "complementary type" and "overlapping type" hybrid mechanisms but failed to construct a cross-regional carbon price linkage model [8].

This paper takes global carbon pricing practices as a reference, focuses on the collaborative optimization path of China's carbon market and policies, and fills the research gap through the following innovation points.) Constructing a multi-case comparison framework, integrate data from the EU ETS, Canada's carbon tax, and China's pilot markets, and quantify the differences in enterprise cost elasticity and emission reduction efficiency under different mechanisms. Introducing a carbon footprint tracking model for the industrial chain to analyze the impact of carbon prices on technological choices and location transfers in key industries such as steel and cement. Designing the Policy Synergy Index (PSI) to evaluate the combined effect of carbon tax rebates, free quotas and green certificate trading. The full text structure is as follows. The second part analyzes the types of carbon pricing and the current implementation status; The third and fourth parts respectively explore the economic and environmental effects; The fifth part puts forward suggestions for policy optimization.

2 Types and Implementation Status of Carbon Pricing Mechanisms

The global carbon pricing mechanism mainly consists of three categories， including carbon tax, carbon trading and hybrid models. The design and implementation paths of these mechanisms vary depending on the regional economic development level, industrial structure and emission reduction targets. As of 2024, 75 countries and regions around the world have implemented carbon pricing tools, covering 24% of greenhouse gas emissions [3, 5]. Among them, the EU Emissions Trading System (EU ETS) and the Canadian federal carbon tax are two typical models, while China explores the application path of the hybrid mechanism through pilot projects and connections with the national market [6].

2.1 Carbon Tax: A Cost-Driven Emission Reduction Tool

Carbon tax directly increases the cost of carbon emissions through a fixed tax rate, compelling enterprises and consumers to transform their behaviors. For instance, since the implementation of the federal carbon tax in Canada in 2019, the tax rate has been increasing year by year to 50 Canadian dollars per ton of CO_2in 2023, driving up gasoline prices by 10% and adjusting the structure of household energy expenditures by 12% [2,3]. Nordic countries (such as Finland and Sweden), as pioneers in carbon taxation, balance emission reduction efficiency and social equity through differentiated tax rate designs (such as tax reduction and exemption for the industrial sector). Studies show that the carbon tax policy has a significant effect on reducing emissions in high energy-consuming industries (such as cement and steel) in the short term, but it may increase the energy burden of low-income groups [7,8]. World Bank data shows that in 2024, the average price of 39 carbon tax tools worldwide was $48 per ton of CO_2, covering only 5% of global emissions and concentrated in high-income countries [3,9].

2.2 Carbon Trading (ETS): A Market-Oriented Flexible Mechanism

Carbon trading achieves emission reduction targets through total volume control and quota trading. As the world's largest carbon market, the EU ETS's carbon price exceeded 100 euros per ton in 2023, driving the power industry to reduce emissions by 43% compared to 2005 [2,5]. Its success is attributed to three major mechanisms. Firstly, tighten the total quota in stages (with an average annual decrease of 2.2%), Secondly, the auction ratio has gradually increased to 60%. Finally, the Carbon Border Adjustment Mechanism (CBAM) is introduced to prevent carbon leakage [2,6]. Since the launch of China's national carbon market in 2021, the trading volume reached 410 million tons in the first year. However, there were problems such as loose quota allocation (97% free) and large price fluctuations (40-60 yuan/ton) (1,4). In contrast, South Korea's ETS stabilizes carbon prices by dynamically adjusting the quota reserve pool (10%-15%), while the Regional Greenhouse Gas Initiative (RGGI) in the United States enhances policy synergy through reinvestment of revenue (80% for energy efficiency projects) [9].

2.3 Hybrid Mechanism: Policy Synergy and Dynamic Optimization

The hybrid mechanism takes into account both the certainty of emission reduction and the controllability of costs by combining carbon taxes and carbon trading tools. International practices can be classified into two types: complementary mechanisms and overlapping mechanisms. The former advocates that carbon taxes cover scattered emission sources (such as buildings and transportation), and that carbon trading controls key industries. For instance, France levies a carbon tax of 44.6 euros per ton on non-ETS industries and alleviates social conflicts through a tax rebate mechanism [4,6]. The latter leans towards dual control over key industries to enhance the intensity of emission reduction. Since 2021, the UK has simultaneously imposed a carbon tax (18 pounds per ton) and an ETS on the power industry, filling the gap of market failure through a "minimum carbon price" mechanism [8]. Pilot regions in China (such as Shanghai) have explored the linkage between carbon financial derivatives (such as carbon quota pledge loans) and green certificate trading, but the problem of cross-regional market segmentation still remains to be solved [1,6].

The global carbon pricing mechanism shows several major trends. First, the coverage is expanding. For instance, emerging economies such as Brazil and India are accelerating the introduction of carbon taxes or ETS, while the prices are gradually converging. The European Union and Canada promote carbon price linkage through the "Climate Club". In addition, policy tools are gradually coordinating. Carbon pricing is combined with green subsidies and technological innovation funds. For example, Germany invests 50% of its carbon market revenue in the research and development of renewable energy [2,5,9]. However, currently only 1% of carbon pricing tools comply with the 1.5 ° C pathway requirements of the Paris Agreement, and developing countries face challenges such as insufficient data monitoring capabilities and the risk of international carbon barriers [3,6].

3 Economic Effects of Carbon Pricing: Multi-dimensional Influences and Dynamic Balance

The economic effect of the carbon pricing mechanism is significantly multi-dimensional and complex. It is manifested not only in the reshaping of industrial structure, technological innovation and job market, but also involves regional development differences and the reconstruction of international competitiveness. Based on global practices and China's experience, this section conducts an analysis from three dimensions: efficiency optimization, fair distribution, and growth momentum.

3.1 Industrial Structure Adjustment and Efficiency Optimization

Carbon pricing guides production factors to flow towards low-carbon fields through cost signals, promoting the systematic reconstruction of the industrial structure. Take the EU ETS as an example. After the carbon price exceeded 100 euros per ton in 2023, the power industry accelerated the phase-out of coal-fired power plants, and the proportion of clean energy in power generation increased to 65% [3,6]. China's national carbon market forces the steel and cement industries to optimize their production processes through quota trading prices (with an average price of 70.14 yuan per ton in May

2025). For instance, the application of hydrogen metallurgy technology by Hebei Iron & Steel Group has reduced carbon emissions per ton of steel by 40% [9]. This process conforms to the transmission path from cost improvement to technological enhancement and then to structural upgrading, and the effect is also obvious. For every 10% increase in carbon prices, the proportion of green technologies in capital expenditure of energy-intensive industries rises by 2.3 percentage points [5]. However, policy design needs to balance efficiency and fairness. For example, although the free quota allocation for the protection of the steel industry alleviated the short-term impact, it also slowed down the speed of low-carbon transformation [1,10].

3.2 Technological Innovation-Driven and Growth Transformation

Carbon pricing stimulates technological innovation through a dual mechanism. First, direct cost pressure forces enterprises to develop emission reduction technologies. For instance, Canada's carbon tax has driven an average annual growth rate of 15% in carbon capture and storage (CCUS) investment [4]. It has also formed a positive cycle by reinvesting the proceeds from carbon trading. The European Union has allocated 60% of its auction revenues to green technology funds, which has led to a 70% reduction in wind power costs within a decade [6]. China's pilot carbon market provides innovative financing for enterprises through carbon financial derivatives (such as quota pledge loans). By 2024, the related financing scale of Shanghai's carbon market exceeded 5 billion yuan, supporting the implementation of demonstration projects such as hydrogen energy steelmaking [9]. Empirical research shows that for every 1% increase in carbon price, the number of green patents of enterprises increases by 0.8%, and the contribution rate of technological innovation to GDP can reach 0.3% [8,11]. However, there is industry heterogeneity in technology diffusion. The technology substitution elasticity of the chemical industry is 40% lower than that of the construction industry, and industry-specific support policies are needed [3, 7].

3.3 Regional Synergy and Distribution Effects

The economic effect of carbon pricing shows significant regional differences. In the European Union, the Carbon Border Adjustment Mechanism (CBAM) has intensified industrial competition between North and South Europe. In 2024, steel enterprises in Southern Europe will face a 12% loss of export share due to increased carbon costs [6]. China has explored regional compensation mechanisms through "east-west carbon sink trading". For instance, the Yunnan Forestry carbon sink project sold 2 million tons of quotas to eastern provinces, and the proceeds were used to support local ecological poverty alleviation [10]. In terms of distribution fairness, the carbon tax may increase the burden on low-income groups (with the proportion of energy expenditure rising by 5%, but Canada has effectively alleviated social conflicts by using 70% of its revenue for household subsidies through "carbon tax rebates" [4,5]. Developing countries need to be vigilant against the "green gap". For instance, India's carbon market covers less than 10% of the country's emissions, and small, medium and micro enterprises find it difficult to participate due to high monitoring costs [7].

3.4 International Competitiveness and Carbon Leakage Risk

The impact of carbon pricing on trade competitiveness depends on policy synergy. The combination of the EU ETS and CBAM has increased the carbon cost of domestic steel enterprises by 8% but maintained their market share through a green premium (a 15% increase in the price of low-carbon steel materials) [6, 9]. The Turkish steel industry has reduced its carbon intensity by 20% through the recycling of scrap steel, reducing its export carbon tariff burden by 25% compared to its Chinese counterparts [4]. China needs to be vigilant against the "double squeeze" .On the one hand, the carbon price in the European Union (100 euros per ton) is ten times that of the Chinese market, which may trigger the return of high-carbon industries; On the other hand, the US Inflation Reduction Act has weakened the competitiveness of China's new energy products through 369 billion US dollars in green subsidies[10]. The response strategies include establishing a "carbon tax - carbon trading" linkage mechanism, implementing differentiated tax rebates for export enterprises, and enhancing the discourse power of rules through the interconnection of carbon markets along the Belt and Road Initiative [11].

3.5 Employment Structure Transformation and Social Costs

Carbon pricing drives "disruptive creation" in the job market. The German carbon market has created 120,000 new jobs in the renewable energy sector, but the number of positions in the traditional energy industry has decreased by 8% [6]. Under China's "dual carbon" goals, it is estimated that there will be 40 million green jobs by 2030, but the average cost of job transfer training for coal and power workers is 50,000 yuan per person [9]. In terms of social costs, for every 10 yuan per ton increase in carbon prices, the compliance costs for small and medium-sized enterprises rise by 3%. They need to enhance their participation through carbon financial tools (such as blockchain traceability to reduce verification costs by 40%) [10]. In addition, the integration of carbon pricing and the digital economy has given rise to new occupations. For instance, the demand for carbon asset managers has increased by 300% in three years, promoting the upgrading of the human capital structure [8].

4 Environmental Effects of Carbon Pricing: Emission Reduction Pathways and Ecological Resilience

The environmental effects of carbon pricing are not only reflected in the absolute reduction of carbon emissions, but also drive the reconstruction of the energy system, the restoration of ecosystems and the improvement of climate adaptability. This section, based on global practices, analyzes the compound impact mechanism of carbon pricing on the ecological environment from three perspectives including direct emission reduction, structural transformation, and collaborative governance.

4.1 Direct Emission Reduction Effect: Differentiated Performance of Policy Tools

The emission reduction paths of carbon tax and carbon trading systems show significant differences. The EU ETS has driven the power industry to reduce emissions by 43% compared to 2005 through the linkage of total quota constraints and carbon price signals (European Environment Agency, 2023), without causing carbon leakage or industrial transfer [3,4]The microscopic data analysis of Colmer shows that the carbon emissions per unit output value of regulated enterprises are reduced by 17.4% through process optimization (such as waste heat recovery), which verifies the incentive effect of market mechanism on technological innovation. In contrast, Canada's carbon tax reduces gasoline consumption by 12% through price transmission mechanism, but subject to tax exemption policies (such as fuel tax exemption in agricultural sector), the actual emission reduction efficiency is 20% lower than the theoretical value. In May 2025, the carbon price of China's national carbon market exceeded 70 yuan/ton, which pushed the carbon emission intensity of the first batch of 2,225 power companies to decrease by 7.3% compared with 2020. However, the high proportion of free quotas (97%) led to the marginal emission reduction cost being lower than the carbon price, which inhibited the deep emission reduction motivation.

4.2 Energy Structure Transformation: Breakthrough of Clean Technology Diffusion and Locking-in Effect

Carbon pricing accelerates the substitution of fossil energy by reconstructing the energy cost curve. In the fourth stage of ETS (2021-2030), 60% of the auction proceeds will be invested in the renewable energy fund, which will push the cost of wind power down by 70% in ten years, and wind power generation will account for 41% in 2024. The cooperation mechanism between China pilot carbon market and green electricity trading has achieved initial results. In 2024, the premium of low-carbon aluminum in Shanghai carbon market reached 120 yuan/ton (carbon price × carbon footprint per unit product), which forced the utilization rate of green electricity in electrolytic aluminum enterprises to increase to 35%. However, the technology lock-in effect still remains a challenge: due to the long payback period (8-12 years) of the investment in hydrogen steelmaking equipment, only 12% of the production capacity in Germany will complete the low-carbon transformation in 2024, and the technology conversion cost needs to be compensated by the carbon difference contract (CCFD).

5 Conclusion

The economic and environmental effects of carbon pricing mechanism are obviously complex and dynamic. Through the systematic analysis of global practice and China case, this paper shows that, firstly, carbon pricing drives emission reduction through the dual paths of cost internalization and technological innovation, but the choice of policy tools needs to match the characteristics of the industry (for example, carbon tax is more efficient for decentralized emission sources, and carbon trading is suitable for large-scale control). Secondly, the design of differentiation mechanisms is the key to balance efficiency and fairness. For example, the redistribution of quota auction income of ETS in the European Union reduces social welfare losses by 23%, while the carbon tax refund mechanism in Canada effectively relieves the burden of low-income groups. Thirdly, the collaborative challenge of international carbon barriers (such as CBAM) and domestic industrial transformation requires that the carbon pricing mechanism be embedded in a wider policy network, such as the deep integration of China's "double carbon" goal and digital economy strategy.

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