Received: 30 August 2023 | Revised: 30 October 2023 | Accepted: 12 November 2023 | Published online: 28 November 2023

RESEARCH ARTICLE

Green and Low-Carbon Economy
2023, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE32021618

Duopoly with Limited Rationality in Carbon Market: A Comparison of Carbon Quota Trading and Carbon Tax System

Yu Chang[1,*]

[1]*School of Business Administration, Zhongnan University of Economics and Law, China*

Abstract: China has established a nationwide carbon quota trading market. Drawing upon international experiences and the strategic vision of the Chinese government, it is anticipated that China will soon incorporate a carbon tax system. I have employed the term "futurescape" to describe a hypothetical future scenario where China's carbon quota trading market and carbon tax system may evolve in parallel. This term is used to emphasize the anticipation and envisioning of potential future circumstances, particularly when discussing the possibility of two different carbon emission management systems – the carbon trading market and the carbon tax system – being implemented concurrently. In this context, "futurescape" represents a forward-looking and strategic perspective, helping to convey predictions and considerations about future policy trends. It not only enhances the depth of exploration into potential future policy options in my research but also indicates the foresight and innovativeness of the study. This paper constructs a repeated oligopoly game model to juxtapose equilibrium points under both carbon trading and tax regimes. Through rigorous analysis, it is discerned that under a duopoly with bounded rationality and inelastic pricing, if the carbon tax is set referencing the clearing price of the carbon market, then both the carbon trading and tax regimes can achieve identical emission reduction outcomes. Stemming from this revelation, for regions with established inelastic, oligopolistic carbon markets, it would be prudent to manage emission sources not included in the carbon market by setting a carbon tax in line with the market's clearing emission price. Furthermore, measures might be considered to dismantle such oligopolistic dominance to enhance emission reduction efficiency or to transition from the carbon market to a tax regime for cost-efficient administration. For regions yet to embrace a carbon pricing mechanism, if there is an anticipation of forming an oligopolistic and inelastic carbon market, given the lower administrative costs, diminished enterprise operational risks, and broader coverage of the carbon tax regime, the region should gravitate toward the carbon tax system as a priority.

Keywords: carbon quotas, carbon tax, oligopoly, repeated game

1. Research Background

The urgency to mitigate global climate change is escalating, necessitating immediate action to reduce greenhouse gas emissions. As a leading emitter, China's efforts in emission reduction are crucial for both its own environmental health and global climate goals. By mid-2021, China established a national carbon trading market and indicated plans for a carbon tax, aiming for a combined positive impact. However, the practical application of these initiatives in China remains contentious and uncertain.

This paper examines the optimal use of carbon market systems and carbon taxes in China, considering its unique economic and environmental context. It analyzes when each approach is most effective, beyond theoretical aspects, considering governmental policy feasibility, business market positioning, and sustainable development. The study compares the carbon market and tax system's real-world impact on emissions reduction and cost management within China's distinctive market, characterized by a duopolistic structure, bounded rationality, and price stability. The findings aim to guide China's carbon pricing strategy. This research is significant for providing the Chinese government and businesses with a basis for strategic planning in carbon market and tax environments. It also addresses gaps in understanding the coexistence of these systems in China, offering insights for future research and contributing to global efforts in reducing greenhouse gas emissions.

This research fills gaps in existing literature by deeply comparing carbon trading and tax systems within specific market contexts, a less explored area in previous studies like those by Jia and Wang (2021), Fu et al. (2018), and Chen (2022). It introduces an oligopolistic market model, inspired by Von Neumann and Morgenstern (1944), to analyze these systems in a unique market setting. Unlike prior works that separately considered emission reduction strategies or management costs, this study evaluates both aspects together, considering market inefficiencies in oligopolistic environments. This approach provides a comprehensive reference for decision-makers on the effectiveness and cost management of carbon reduction systems. Additionally, the study is particularly relevant for China, the world's largest carbon emitter, as it transitions to a dual system of carbon trading and taxation, highlighting its growing role in the global carbon market.

1.1. Introduction to carbon valuation system

The carbon pricing mechanism includes carbon market and carbon tax systems. The carbon market, based on Coase's

*Corresponding author: Yu Chang, School of Business Administration, Zhongnan University of Economics and Law, China. Email: 1436534924@qq.com

Table 1
Comparison of carbon market and carbon tax

Attributes	Carbon market	Carbon tax
Advantages	- Establishing a reasonable carbon emission pricing (Shang, 2013) - Allows for precise control of total carbon emissions (Wei, 2015) - Can span different regions and countries to create a unified large market (Zhang, 2022) - Can be combined with tools such as futures for intertemporal allocation (Tian, 2021) - Relatively lower implementation resistance	- Low cost - Quick to take effect - Strong binding force - Low government management cost (Wang, 2019) - Stable tax rates, reducing business risk - Can increase government revenue, with broad coverage (Fu et al., 2018)
Disadvantages	- High risks and costs (Kuang, 2014) - High government management costs (Sun, 2022) - Market uncertainty and the risk of market failure (Hai, 2016) - Risks of arbitrage, carbon leakage, and rent-seeking by enterprises - Greater price volatility, increasing business operational risks	- Relatively weak emission reduction effects - Increased corporate costs, facing significant societal resistance (Carattini et al., 2018) - Unreasonable tax rates can lead to efficiency losses
Commonality	Both are mechanisms aimed at reducing carbon emissions	
Differences	Mainly in control methods, cost, efficiency, and implementation scope	

theorem, controls emissions through trading allowances within a regulated total quantity. Carbon taxation, grounded in the concept of a "Pigouvian tax" from welfare economics, regulates emissions by taxing a company's carbon emissions. Both systems aim to internalize the cost of carbon emissions in a company's operations, promoting energy efficiency and emissions reduction for profit maximization. However, they differ in effectiveness, cost, regulatory scope, governance, and implementation challenges. These differences, along with their respective pros and cons, are detailed in Table 1:

Global carbon pricing systems are expanding, with an increasing trend in the coverage of carbon emissions by these systems, except for a decline during the pandemic in 2020, as illustrated in Figure 1. This growth has led countries to focus more on the uncertainties in carbon market prices and the overall costs of carbon pricing mechanisms. Concurrently, there is a rising trend in companies adopting internal carbon pricing to meet emission reduction goals. In 2020, 853 companies reported using internal carbon pricing, a 20% increase from 2019, and an additional 1159 companies plan to implement it within the next 2 years, according to the World Bank (2021) report on carbon pricing mechanisms.

1.2. The current development of China's carbon pricing system

China's carbon pricing framework, despite having the world's largest national carbon market in greenhouse gas coverage, is limited to only 40% of emissions from its energy sector, less extensive than carbon markets in regions like the EU, California, Washington State, Tokyo, South Korea, and Indonesia. China's market started with local pilots in 2011 and launched nationally in 2021. Since then, trading volume has grown, with prices fluctuating between 55 and 62 RMB/ton. The market, covering 189 million tons with a 99.5% compliance rate, faces challenges like low trading activity and the need for enhanced market effectiveness and management mechanisms. Its focus on the power sector, excluding other high-emission industries, limits its overall impact, and exposes these industries to potential "carbon tariff" risks. China needs to develop financial tools for efficient resource allocation in the carbon market and refine administrative aspects like emission benchmarks, regulatory bodies, and carbon quota allocation.

1.3. Prediction of China's carbon pricing system in the future

It is projected that China will soon adopt a dual approach of carbon market systems and carbon taxation to mitigate emissions. This forecast hinges on the following four reasons:

(1) International Experience Advocates Dual Implementation:

The concurrent use of carbon markets and carbon taxes is aligned with global practices. In the EU, most countries complement their carbon trading system (EU ETS) with carbon taxes, integrated into consumption or environmental taxes. The EU is also considering a unified carbon tax. Research shows that carbon taxes in Europe reduced emissions by 2.8%–4.9% from 2008 to 2018. Among the Paris Agreement's 185 parties, 97 are implementing or planning to implement carbon tax policies.

Studies, like Freire-González (2018) on Germany, demonstrate that combining carbon taxes with other reforms can offset negative economic impacts of emission constraints, reduce tax levels, lower emission reduction costs, and positively affect labor demand. Böhringer et al. (2003) also highlight the benefits of joint implementation in mitigating the adverse effects of emission constraints.

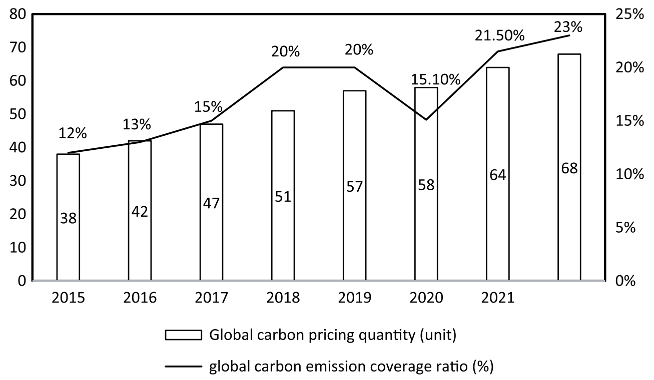
In India, combining these approaches enhanced power sector efficiency and reduced electricity prices. Li and Jia (2017) research, specifically on China, indicated that a hybrid policy of carbon taxes and trading systems could significantly reduce primary energy consumption and help China peak its carbon emissions before 2030.

Overall, these findings suggest that the joint implementation of carbon markets and carbon taxes is an effective climate change mitigation strategy with positive economic and employment impacts, supporting their simultaneous use.

(2) Preventing Carbon Leakage Issues:

Implementing only carbon markets without carbon taxes risks carbon leakage, as markets might not include all enterprises,

Figure 1
Number of implemented carbon pricing mechanisms worldwide and their coverage of carbon emissions



particularly smaller ones and mobile emission sources. In regions with only carbon trading and no tax, carbon emissions could shift to non-participating enterprises, undermining emissions control. Studies supporting this include Eichner and Pethig (2011) research, which shows that emission limits can cause carbon leakage, varying with different factors and elasticities. Antimiani et al. (2013) suggest that unilateral policies might be ineffective in reducing leakage rates, implying the need for global cooperation and additional measures like carbon taxes. Barker et al. (2007) found that carbon emission trading systems might not cause extensive leakage due to local market factors, but this does not negate the potential risk. Antoci et al. (2021) recommend considering policy design features like emission caps and permit pricing, indicating the benefit of combining markets with other policies. Burniaux and Oliveira Martins (2012) stress the importance of global carbon markets and warn that unilateral policies could lead to leakage, especially with rising future carbon prices. Therefore, a comprehensive strategy including both carbon markets and taxes is essential for effective climate change mitigation.

(3) Managing Carbon Emissions of Small and Micro-enterprises

China's carbon neutrality goal under the "30–60" plan necessitates effective carbon emission management in small and micro-enterprises, which might struggle to integrate into carbon markets. Carbon taxation is seen as a necessary tool for this. Xu et al. (2022) study shows that energy-saving and emissions reduction policies in pilot cities have effectively reduced carbon emissions in these enterprises over time. Yao et al. (2019) research emphasizes the significant carbon footprint of small and micro-enterprises and the importance of market-driven environmental improvement mechanisms, suggesting that knowledge sharing can aid emissions reduction.

Wei et al. (2022) literature review underlines China's efforts in guiding the low-carbon transition, particularly for small and micro-enterprises. Wang et al. (2022) research finds that carbon trading policies have a substantial and sustainable impact on achieving carbon neutrality, aiding in reducing carbon sources and increasing carbon sinks through various strategies.

These studies collectively highlight the importance of managing emissions in small and micro-enterprises as part of China's carbon neutrality strategy, suggesting that a combination of carbon trading policies and other measures is essential for reaching these goals.

(4) Government Policy Vision and Scholarly Support

The Chinese government has been actively considering carbon taxation. In 2010, the National Development and Reform Commission and the Ministry of Finance proposed a carbon tax framework in their "Special Report," suggesting a fixed tax rate on carbon dioxide emissions. The 2021 "Action Plan for Carbon Peak by 2030" and the 2022 "Implementation Plan for Promoting Green Consumption" further indicate plans to use taxation to promote low-carbon development.

Research supports carbon taxation's effectiveness. Dong et al. (2017) study, using a model across 30 provinces, shows that carbon taxes can significantly reduce emissions in key industries like electricity, metals, and chemicals. Ding et al. (2019) research using an energy technology diffusion model suggests that high carbon taxes could accelerate technology substitution and help China reach its emission peak before 2030.

Liu et al. (2021) study, based on a computable general equilibrium model, finds that carbon taxes effectively reduce emissions but may impact economic growth and welfare. However, a well-designed carbon tax revenue recycling mechanism, like reducing personal income tax, could achieve a "double dividend" of emission reduction and economic benefits.

In conclusion, the Chinese government's pursuit of carbon tax policy is seen as a crucial element in emission reduction and environmental improvement, but it needs to be balanced with other measures to mitigate potential economic downsides. These studies provide a strong foundation for developing and implementing carbon taxation in China.

2. Research Questions and Literature Review

2.1. Literature review

2.1.1. Literature overview

The study defines key economic concepts and reviews literature on carbon pricing strategies. Oligopoly is a market with a few firms controlling significant market share, discussed by Friedman (1982) using Cournot and Chamberlin models. Bounded rationality, introduced by Simon (1997), explains non-rational economic decisions due to limited information and cognitive abilities. Price inelasticity, explored by Andreyeva et al. (2010), refers to demand's weak response to price changes, particularly in food markets. Game theory, as detailed by Von Neumann and Morgenstern (1944), is a mathematical framework for strategic decision-making with broad applications in economics and social sciences.

The literature is grouped into four categories:

1. Carbon Pricing and Emissions Reduction: Tang et al. (2020) focused on marginal abatement costs within China's ETS and optimal pricing, while Markard (2022) discussed policy combinations for sustainable transitions.
2. Carbon Markets and Pricing Mechanisms: Li et al. (2022) investigated determinants of carbon markets and energy consumption changes, and Pan et al. (2023) used text mining for carbon price forecasting.
3. Policy Integration: Wang et al. (2023) used experimental economics to offer recommendations for integrating carbon trading and taxation policies.
4. Future Directions: Scholars predict a parallel use of carbon markets and taxes, with Liu (2022) and Chen (2022) noting their synergistic potential, especially in market quota allocation and price regulation.

This body of work supports the coordinated use of carbon markets and taxes to enhance emission reduction strategies.

2.1.2. Analysis

The literature synthesis above furnishes a comparative analysis of carbon tax and carbon trading systems across diverse facets, buttressing the viewpoints posited in the conclusion. These studies proffer profound insights and guidelines for governments, businesses, and researchers when discerning between carbon market and carbon tax systems.

2.1.3. Deliberations

Past literature on carbon pricing systems has notable strengths and weaknesses. Strengths include a holistic approach, covering carbon emission mitigation, economic growth, income distribution, optimal pricing, and sectoral coverage. The diversity of research topics, including emission reduction impacts, carbon market mechanics, and policy integration, offers a comprehensive view of carbon reduction strategies. Practicality is another strength, providing valuable insights and guidelines for decision-makers. Case studies, such as China's ETS and text mining for carbon price forecasting, enhance real-world understanding.

However, weaknesses exist. One is the lack of detailed analysis under specific market conditions. Methodologically, there is an overreliance on traditional tools, with limited use of innovative approaches like game theory. Lastly, there is insufficient consideration of administrative costs and practical applicability, leading to a gap between theory and practice.

2.1.4. Evidentiary matters pertinent to the conclusions

This paper contributes to the literature by analyzing the differences and similarities between carbon trading and carbon tax systems, applying game theory for a novel perspective, and balancing emission reduction with management costs. Economically, Hou (2022) finds that carbon trading may increase the value of high-carbon industries but could lead to higher costs and prices. Carbon taxes might have a broader economic impact, potentially raising production costs and prices, as shown by Dissou and Karnizova (2016). Xu (2022) notes that both systems may initially decrease consumer surplus and business profits, but they could lead to a higher economic equilibrium over time.

Environmentally, Duan and Yang (2017) report that a carbon market could reduce emissions in China's electricity sector but also risk carbon leakage, while Wittneben (2009) suggests carbon taxes could be more effective for emission reductions. Dong and Li (2020) find that both systems can significantly lower carbon emission intensity.

In terms of fairness, Fang and Tang (2022) highlight potential fairness issues with carbon trading affecting non-state-owned enterprises, while Zhu and Sun (2022) indicate variable impacts of carbon trading on resource allocation across regions and industries. Additionally, Duan and Yang (2017) raise concerns about the impact of a carbon market on low-income groups.

The review compares carbon taxes and trading, providing insights and guidance for stakeholders in choosing between the two systems.

2.2. Research questions

China plans to use both carbon market and carbon tax systems for emissions reduction. The carbon tax system is known for its low management costs and quick implementation, while the carbon market system is more effective for emissions reduction. To determine which system should be prioritized, it is essential to analyze specific scenarios, comparing their emissions reduction effectiveness and management costs. This paper focuses on a specific situation characterized by a duopolistic market, bounded rationality, and price inelasticity. It examines whether the carbon market or carbon tax system is more suitable in this context, assessing their respective impacts on emissions reduction and management costs. The rationale for choosing this model is explained in detail in this paper.

3. Modeling and Analysis

3.1. Model selection reasoning

To simulate the characteristics of China's regional carbon market, this paper adopts assumptions of duopoly, exogenous prices, and bounded rationality. It assumes that the initial carbon quotas are allocated by the Chinese government for free, there are no intertemporal trades in the carbon market, and transaction costs are set to zero. The rationale for these assumptions is as follows:

(1) Duopoly Model: This study adopts a duopoly model to simulate China's carbon market, based on observations from 2013 to 2020 in regions like Fujian, Tianjin, and Chongqing. These areas showed low enterprise participation and limited price elasticity in carbon trading pilot programs. A report by the China Carbon Trading Network (October 26, 2023) indicated a concentration in the electricity sector, with similar marginal abatement costs among enterprises, leading to trading inactivity. The initial high trading volume at the launch of China's carbon market in July 2021 quickly declined, reflecting market efficiency doubts and resulting in low liquidity. China's carbon market has an annual turnover rate of just 1.5%, much lower than the EU's 52.8%. These characteristics suggest a duopoly rather than a perfectly competitive or monopolistic market. The assumption of a repeated duopoly game is used, fitting the market dynamics where two dominant firms potentially influence prices through strategic behavior.

(2) Exogenous Prices: The use of exogenous prices in this paper is informed by prior research and the dynamics of the Chinese regional carbon market. Studies like Pan et al. (2021) and Jung et al. (2023) have utilized game models in the context of carbon markets. Pan et al. used a two-player game to explore the impact of carbon emissions on green technology decisions and product prices, while Jung et al. investigated a binary duopoly market with firms using polluting and eco-friendly inputs. These studies, employing duopoly game models to simulate market behavior in carbon emissions trading systems, align with this paper's research context and objectives. Hence, they provide a theoretical foundation for this paper's choice of a repeated duopoly game model and validate the assumption of exogenous prices.

(3) Bounded Rationality: In reality, individuals and firms often make decisions that are not fully rational due to incomplete information and limited information processing capabilities. Even in the case of repeated games, it can be challenging to predict opponents' strategies and make optimal responses. Hence, the assumption of bounded rationality is reasonable and closer to real-world situations. Therefore, this paper investigates a closed, bounded rational, repeated duopoly market where multiple rounds of games take place.

For the carbon trading system, it assumes free initial carbon quota allocation by the government, mirroring China's actual approach.

Transaction costs are excluded from the model for simplicity, a method also used in studies like Wara (2007) and Kossoy and Guigon (2012) to facilitate easier analysis.

Regarding the carbon tax system, this paper follows the "Special Report on the Design of China's Carbon Tax System" by the China National Development and Reform Commission. It assumes a uniform tax rate on all carbon emissions, consistent with the principles of "uniformity, low starting point, periodicity, and dynamism" suggested by Mao (2017). Liu and Zhang (2019) also support a uniform tax rate based on actual emissions for effective control, in line with China's commitments under the Paris Climate Agreement. This paper, therefore, posits a uniform carbon tax applied to all emissions per unit.

3.2. Model assumptions

(1) Assuming that there are two oligopolistic enterprises producing identical products in a closed market, both of which are free to choose their production volume. Let $q_i(n)$ denote the production volume of the i−th enterprise in period n, and the total production in the market at that time is $Q(n) = q_1(n) + q_2(n)$. The demand function remains unchanged in different periods and is given by $p = f(Q) = a - bQ\,(a, b$ are non-negative);

(2) Enterprise I is a follower-type enterprise with higher production costs, which are a function of the production volume, $C_1(q) = c_1 q_1^2 (c_1 > 0)$. Enterprise II is a leader-type enterprise with lower production costs, which are also a function of the production volume, $C_2(q) = c_2 q_2 (c_2 > 0)$;

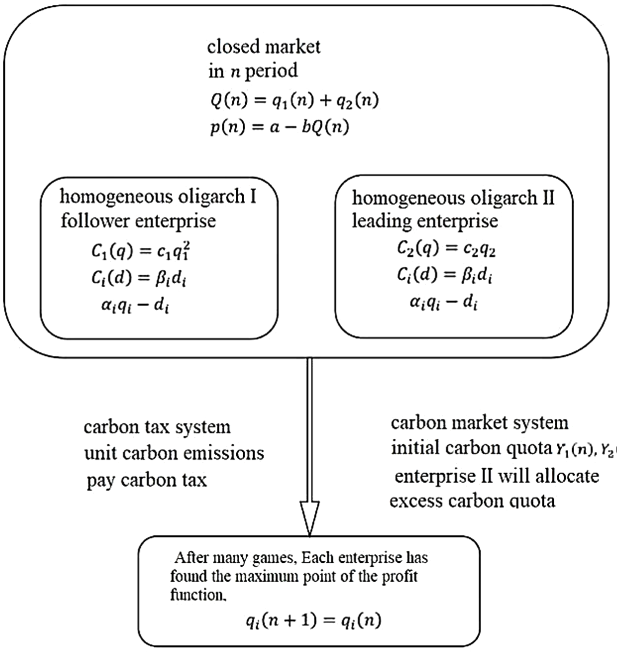
(3) Both enterprises have the same cost for reducing carbon emissions. Suppose enterprise i has to reduce its carbon emissions by d_i, and the cost of reducing emissions is a function of d_i, $C_i(d) = \beta_i d_i$ (where $\beta_i > 0$, and β_i may differ between the two enterprises). The amount of carbon emissions is linearly related to the production volume, $\alpha_i q_i$ (where $\alpha_i > 0$, and α_i may differ between the two enterprises). After each enterprise has made efforts to reduce carbon emissions, their respective emissions are $\alpha_i q_i - d_i$ (The two enterprises are located in the same region and employ the same emission reduction technology; hence, the cost of emission reduction is identical. The leader and follower are designated based on the differences in production costs.);

(4) When there is no carbon market system, both enterprises pay a carbon tax P per unit of carbon emitted. With a carbon market system in place, $Y_i(n)$ is the initial carbon quota allocated to the i-th enterprise for free. Assuming that enterprise I emits more carbon than its initial carbon quota, while enterprise II emits less than its initial carbon quota, i.e., $\alpha_1 q_1(n) - d_1 > Y_1(n)$ and $Y_2(n) > \alpha_2 q_2(n) - d_2$, enterprise II sells its surplus carbon quota at a price P. Assuming that P is lower than enterprise I's emission reduction cost β_1, and that enterprise I can hoard the excess carbon quota at no cost instead of using it in the current period, enterprise I will buy all of enterprise II's surplus carbon quota to minimize costs, even if it does not need it in the current period (i.e., even if the carbon quota purchased in the previous period is sufficient to cover all of its emissions in the current period, enterprise I will still buy from enterprise II);

(5) Assuming both enterprises have limited rationality and cannot anticipate the optimal production level, they can only determine the next period's production level based on the sign of the derivative (marginal profit) of the profit function with respect to production in the previous period. If the derivative is positive (marginal profit is positive) in period n, production will be increased in period $n+1$; conversely, if the derivative is negative, production will be decreased. After multiple rounds of game play, each enterprise finds the point where the derivative is zero (the maximum profit point of the profit function), and production stabilizes at $q_i(n+1) = q_i(n)$.

The market structure of the oligopoly market is illustrated in Figure 2, with two homogenous oligopoly firms operating in a closed market, possessing different production costs but the same emission reduction costs. Under a carbon tax or carbon market system, repeated games will be played. Both firms are boundedly rational and will gradually adjust their production over multiple rounds to find the point of maximum profit, resulting in a stable production level and reaching a game equilibrium.

Figure 2
Market structure chart



3.3. Game equilibrium under carbon quota trading system

In the game equilibrium under a carbon quota trading system, the multi-round game of the firms is depicted in Figure 3.

Enterprise I purchases excess carbon quotas from enterprise II, and in the first game, the two firms agree on a price of P. In subsequent repeated games, they will continue to use the same price as before. The profit functions of the two enterprises are as follows:

$$\begin{cases} L_1[q_1(n), q_2(n)] = q_1(n)[a - bQ(n)] - c_1 q_1^2(n) - \beta_1 d_1 - P[\alpha_1 q_1(n) - d_1 - Y_1(n)] \\ L_2[q_1(n), q_2(n)] = q_2(n)[a - bQ(n)] - c_2 q_2(n) - \beta_2 d_2 + P[Y_2(n) - \alpha_2 q_2(n) + d_2] \end{cases}$$

This paper assumes that enterprises can accumulate carbon quotas at no cost, and the price of carbon quotas is lower than the cost of

Figure 3
Multi-round game process under a carbon market system

emission reduction. This incentivizes enterprise I to purchase all the surplus carbon quotas of enterprise II, not just the quotas needed to meet its current demand. In reality, enterprises may also purchase carbon quotas based on the expected price, storage cost, and future cost.

The profit functions of each enterprise in the first period are

$$\begin{cases} L_1(q_1, q_2) = q_1(a - bQ) - c_1 q_1^2 - \beta_1 d_1 - P[\alpha_1 q_1 - d_1 - Y_1] \\ L_2(q_1, q_2) = q_2(a - bQ) - c_2 q_2 - \beta_2 d_2 + P[Y_2 - \alpha_2 q_2 + d_2] \end{cases}$$

By taking the derivative of the profit functions with respect to output and setting the derivative (marginal profit) to zero, the optimal production level of each firm can be obtained.

$$\begin{cases} \frac{\partial L_1(q_1, q_2)}{\partial q_1} = a - 2(b + c_1)q_1 - bq_2 - Pa_1 \\ \frac{\partial L_1(q_1, q_2)}{\partial q_2} = a - bq_1 - 2bq_2 - c_2 - Pa_2 \end{cases}$$

Solving the equations, we get: $\begin{cases} q_1^* = \frac{a-(bq_2 - Pa_1)}{2(b+c_1)} \\ q_2^* = \frac{1}{2b}(a - bq_1 - c_2 - Pa_2) \end{cases}$

Assuming both enterprises have limited rationality, the next period's production will be determined based on the sign of the marginal profit, which is the derivative of the profit function with respect to production from the previous period. If the derivative in period n is positive, then production will increase in period $n + 1$, and if it is negative, production will decrease in period $n + 1$.

Let us assume the expression for the production in period $n + 1$ is as follows:

$$q_{i(n+1)} = A_i q_{i(n)} + (1 - A_i) q_{i(n)} \frac{\partial L_i\left(q_{1(n)}, q_{2(n)}\right)}{\partial q_i}$$

Here, $A_i > 0$ represents the speed at which enterprise i adjusts its production. Substituting $\begin{cases} \frac{\partial L_1(q_1, q_2)}{\partial q_1} = a - 2(b + c_1)q_1 - bq_2 - Pa_1 \\ \frac{\partial L_1(q_1, q_2)}{\partial q_2} = a - bq_1 - 2bq_2 - c_2 - Pa_2 \end{cases}$ into the above expression, we get

$$\begin{cases} q_1(n+1) = A_1 q_1(n) + (1 - A_1) q_1(n)[a - 2(b + c_1)q_1(n) - bq_2(n) - P\alpha_1] \\ q_2(n+1) = A_1 q_2(n) + (1 - A_2) q_2(n)[a - bq_1(n) - 2bq_2(n) - c_2 - P\alpha_2] \end{cases}$$

After several rounds of game, each enterprise finds the point where the derivative is zero, and production remains unchanged from that point onwards: $q_i(n + 1) = q_i(n)$.

Substituting $q_i(n+1) = q_i(n)$ into the above equations, we get

$$\begin{cases} q_1 = A_1 q_1 + (1-A_1) q_1 [a - 2(b+c_1) q_1 - b q_2 - P\alpha_1] \\ q_2 = A_1 q_2 + (1-A_2) q_2 [a - b q_1 - 2b q_2 - c_2 - P\alpha_2] \end{cases}$$

This equation has three solutions:

$$\begin{cases} q_1 = 0 \\ q_1 = 0 \end{cases} \qquad \begin{cases} q_1 = 0 \\ q_2 = \frac{a - c_2 - a_2 P - 1}{2b} \end{cases} \qquad \begin{cases} q_1 = \frac{a - a_1 P - 1}{2(b+c_1)} \\ q_2 = 0 \end{cases}$$

3.4. Game equilibrium under carbon tax system

Under a carbon quota trading system, the multi-period game of the enterprises is shown in Figure 4.

Assuming the carbon tax system levies carbon tax on all carbon emissions by enterprises and adopts a quantity-based tax system (the tax rate per unit of carbon emissions is the same), the profit function of each enterprise is

$$\begin{cases} L_1[q_1(n), q_2(n)] = q_1(n)[a - bQ(n)] - c_1 q_1^2(n) - \beta_1 d_1 - P^*[\alpha_1 q_1(n) - d_1] \\ L_2[q_1(n), q_2(n)] = q_2(n)[a - bQ(n)] - c_2 q_2(n) - \beta_2 d_2 - P^*[\alpha_2 q_2(n) - d_2] \end{cases}$$

The profit function of each enterprise in the first period is

$$\begin{cases} L_1(q_1, q_2) = q_1(a - bQ) - c_1 q_1^2 - \beta_1 d_1 - P^*[\alpha_1 q_1 - d_1] \\ L_2(q_1, q_2) = q_2(a - bQ) - c_2 q_2 - \beta_2 d_2 - P^*[\alpha_2 q_2 - d_2] \end{cases}$$

Taking the derivative of the profit function with respect to production and setting the derivative (marginal profit) to zero, we get

$$\begin{cases} \frac{\partial L_1(q_1,q_2)}{\partial q_1} = a - 2(b+c_1) q_1 - b q_2 - P^* a_1 \\ \frac{\partial L_1(q_1,q_2)}{\partial q_2} = a - b q_1 - 2b q_2 - c_2 - P^* a_2 \end{cases}$$

we get: $\begin{cases} q_1^* = \frac{a - (b q_2 - P^* a_1)}{2(b+c_1)} \\ q_2^* = \frac{1}{2b}(a - b q_1 - c_2 - P^* a_2) \end{cases}$

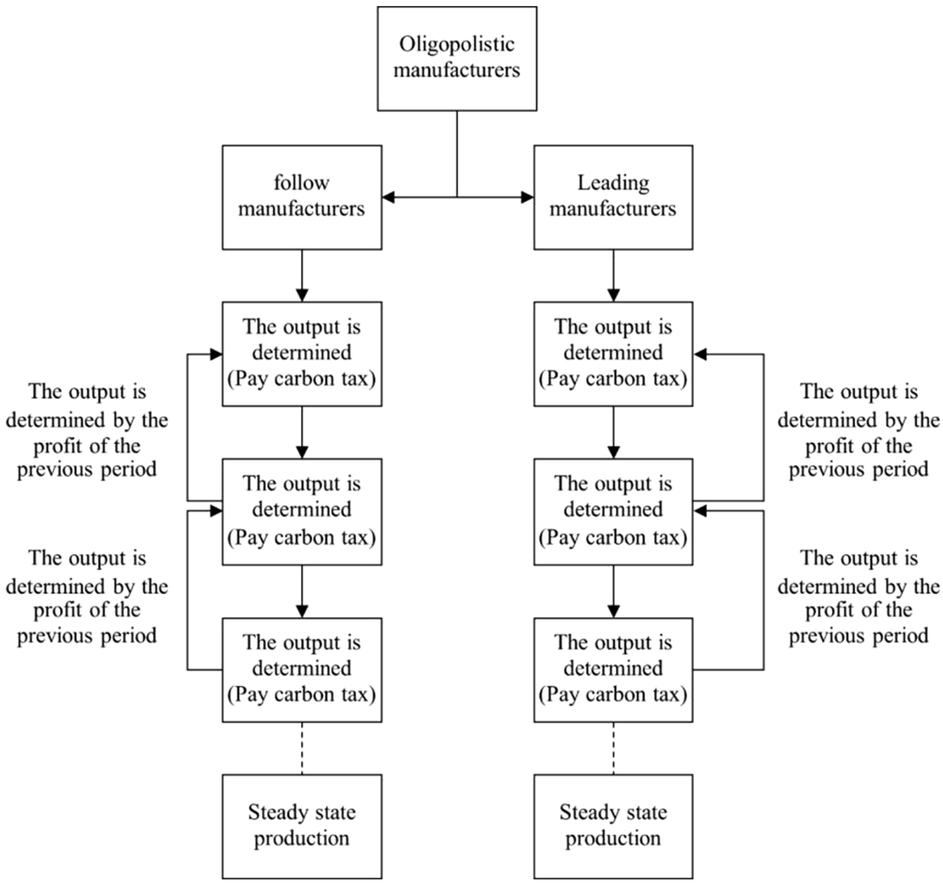
This leads to the short-term equilibrium point.

Substituting $\begin{cases} \frac{\partial L_1(q_1,q_2)}{\partial q_1} = a - 2(b+c_1) q_1 - b q_2 - P^* a_1 \\ \frac{\partial L_1(q_1,q_2)}{\partial q_2} = a - b q_1 - 2b q_2 - c_2 - P^* a_2 \end{cases}$

into the above expression,

$$q_{i(n+1)} = A_i q_{i(n)} + (1 - A_i) q_{i(n)} \frac{\partial L_i\left(q_{1(n)}, q_{2(n)}\right)}{\partial q_i}$$

Figure 4
Equilibrium under a carbon tax system



we get:

$$\begin{cases} q_1(n+1) = A_1q_1(n) + (1-A_1)q_1(n)[a - 2(b+c_1)q_1(n) - bq_2(n) - P^*\alpha_1] \\ q_2(n+1) = A_1q_2(n) + (1-A_2)q_2(n)[a - bq_1(n) - 2bq_2(n) - c_2 - P^*\alpha_2] \end{cases}$$

Setting $q_i(n+1) = q_i(n)$ in the above equations, we obtain

$$\begin{cases} q_1 = A_1q_1 + (1-A_1)q_1[a - 2(b+c_1)q_1 - bq_2 - P^*\alpha_1] \\ q_2 = A_1q_2 + (1-A_2)q_2[a - bq_1 - 2bq_2 - c_2 - P^*\alpha_2] \end{cases}$$

This equation has three solutions:

$$\begin{cases} q_1 = 0 \\ q_1 = 0 \end{cases} \quad \begin{cases} q_1 = 0 \\ q_2 = \frac{a-c_2-a_2P^*-1}{2b} \end{cases} \quad \begin{cases} q_1 = \frac{a-a_1P^*-1}{2(b+c_1)} \\ q_2 = 0 \end{cases}$$

3.5. Comparison of equilibria under carbon quota trading and carbon taxation systems

Under the carbon quota trading system, the game equilibrium is

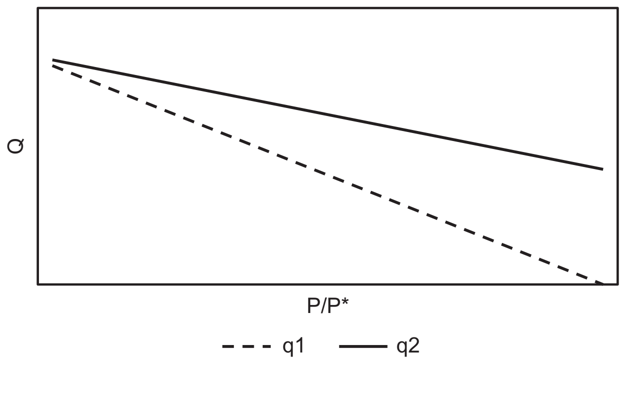
$$\begin{cases} q_1 = 0 \\ q_2 = 0 \end{cases} \quad \begin{cases} q_1 = 0 \\ q_2 = \frac{a-c_2-a_2P-1}{2b} \end{cases} \quad \begin{cases} q_1 = \frac{a-a_1P-1}{2(b+c_1)} \\ q_2 = 0 \end{cases}$$

where P is the price agreed upon by the two companies in the first game. Given the total production $Q(n) = q_1(n) + q_2(n)$, the steady-state total production under the game equilibrium can be any of the following three possibilities: $Q = 0$, $Q = \frac{a-c_2-a_2P-1}{2b}$, $Q = \frac{a-a_1P-1}{2(b+c_1)}$.
The game equilibrium under a carbon tax system is as follows:

$$\begin{cases} q_1 = 0 \\ q_2 = 0 \end{cases} \quad \begin{cases} q_1 = 0 \\ q_2 = \frac{a-c_2-a_2P^*-1}{2b} \end{cases} \quad \begin{cases} q_1 = \frac{a-a_1P^*-1}{2(b+c_1)} \\ q_2 = 0 \end{cases}$$

Here, P^* represents the carbon tax amount per unit of carbon emissions. Under the equilibrium state of the game, there are three possible total production levels: $Q = 0$, $Q = \frac{a-c_2-a_2P^*-1}{2b}$, *and* $Q = \frac{a-a_1P^*-1}{2(b+c_1)}$. Constants a, b, c_1, c_2, a_1, *and* a_2 can be plotted on the total production graph shown in Figure 5.

Figure 5
Relationship between total production and carbon market clearing price/carbon tax price



The graph shows that total output decreases as the carbon market clearing price or carbon tax price increases, with carbon emissions increasing alongside total output. As can be inferred from the model, the game equilibrium under the two systems is the same only when $P^* = P$.

Under the carbon market system, enterprise I emits more than its initial quota, while enterprise II emits less, enabling II to sell excess quotas to I. Since the price P is lower than enterprise I's emission reduction cost β_1, enterprise I opts to buy quotas from II instead of reducing emissions. In the carbon tax system, both enterprises pay a tax fee P per unit of emissions, with output decisions based on prior marginal profits. When the carbon tax price exceeds the carbon market equilibrium price, both enterprises face increased costs (production, emission reduction, and carbon taxes), potentially reducing output to maximize profits.

In summary, when the carbon tax price is higher than the carbon market price ($P^* > P$), the total output under the carbon tax system may be lower than in the carbon market system. This is because the carbon tax system incurs higher costs, leading to reduced output. Conversely, in the carbon market system, enterprises can trade quotas to avoid higher costs, potentially resulting in higher output. Higher output indicates weaker emission reduction effects, and vice versa, as illustrated in Table 2.

Table 2
The impact of carbon tax price and carbon market clearing price on total production and emission reduction

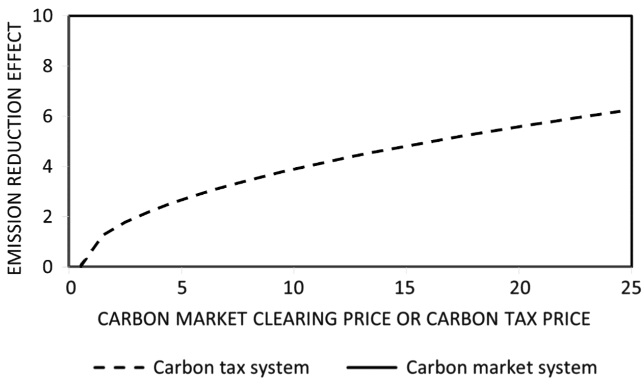
	Total production	Carbon emissions emission	Reduction effect
Carbon tax price > Carbon market clearing	Carbon tax < carbon market	Carbon tax < Carbon market	Carbon tax > Carbon market
Carbon tax price = Carbon market clearing price	Carbon tax = Carbon market	Carbon tax = Carbon market	Carbon tax = Carbon market
Carbon tax price < Carbon market clearing price	Carbon tax > Carbon market	Carbon tax > Carbon market	Carbon tax < Carbon market

The relationship between total production and emission reduction effectiveness is inversely related. Merely pursuing emission reduction effectiveness while neglecting total production is not advisable; instead, a balance should be sought between total production and emission reduction effectiveness. Montgomery (1972) mathematically demonstrated the effectiveness of emissions trading markets in achieving this balance, meaning that emissions trading markets can maximize production under a fixed level of emission reduction. Therefore, the optimal outcome for implementing a carbon tax is to achieve the same level of emission reduction and total production as the carbon market system. Comparing the equilibrium points of the two systems, as long as the carbon tax rate per unit of carbon emissions under the tax system is equal to the market clearance price per unit of carbon allowance under the emissions trading system, the equilibrium points reached by both systems are the same. In this scenario, the carbon tax system can effectively balance emission reduction and total production, minimizing efficiency losses. Regarding a comparison of emission reduction effects between carbon markets and carbon taxes, numerical simulation analysis is conducted here, with environmental parameters modeled based on the research of Wu et al. (2014).

(1) When the emission reduction cost of an enterprise is less than the cost of purchasing emission rights in the carbon market and the cost of paying carbon taxes

At this time, the emission reduction effects of the carbon market and carbon tax are shown in Figure 6.

Figure 6
Company I emission reduction scenario one



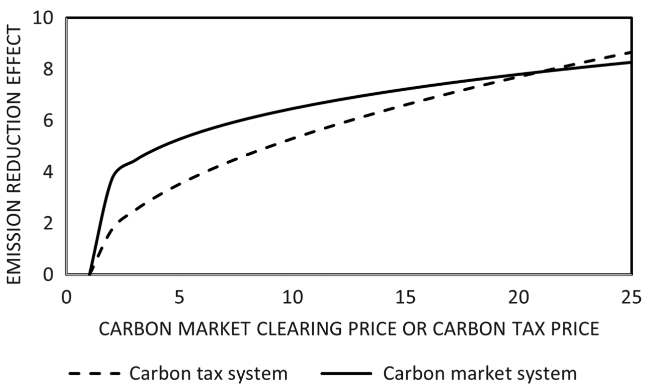
As can be seen from Figure 6, because the cost of emission reduction for the enterprise is less than the cost of purchasing emission rights in the carbon market, the enterprise will not buy emission rights in the carbon market. At this time, the carbon market system fails, and only the carbon tax system can function.

(2) When the emission reduction cost of an enterprise is greater than the cost of purchasing emission rights in the carbon market and less than the cost of paying carbon taxes

At this time, the emission reduction effects of the carbon market and carbon tax are shown in Figure 7.

From Figure 7, it can be observed that due to the profit incentive of the carbon market system for enterprise I to sell surplus carbon emissions rights, the carbon market system is superior to the carbon tax system when the carbon tax price is relatively low. As the carbon tax price increases, the emission reduction effect of the carbon tax system begins to surpass the carbon market system. Since the emission reduction effect is inversely related to the total output, a high carbon tax price, although it can achieve a better emission reduction effect, will inevitably lead to a loss in total output. To balance output and emission reduction effects, the carbon tax price needs to be controlled within a reasonable range. When $P^* = P$, the emission reduction effect of the carbon tax system under this circumstance is the same as the carbon market system.

Figure 7
Company I emission reduction scenario two

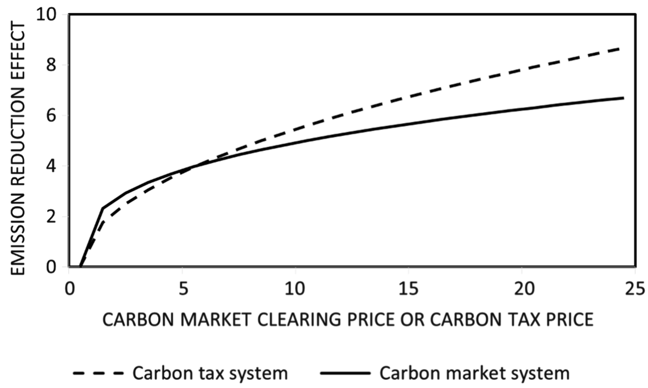


(3) When the emission reduction cost of an enterprise is greater than the cost of purchasing emission rights in the carbon market and the cost of paying carbon taxes

At this time, the emission reduction effects of the carbon market and carbon tax are shown in Figure 8.

As can be seen from Figure 8, because the cost of emission reduction for enterprises is more expensive than buying carbon emissions rights or paying carbon taxes, both purchasing carbon emissions rights or paying carbon taxes are more "cost-effective" options for enterprises than autonomous emission reduction. Enterprises may choose to buy carbon emission rights or pay carbon taxes instead of reducing emissions autonomously. However, this choice may not be the most environmentally friendly because it does not substantially reduce the carbon emissions of the enterprise but transfers the emission rights to other organizations or enterprises, or the money to the government. This situation may require the government to take additional measures, such as increasing the price of carbon emission rights or the tax rate of carbon tax, to further encourage enterprises to reduce their own carbon emissions. At this time, neither the carbon market system nor the carbon tax system has played a role in promoting enterprise emission reduction. Because the selling price of carbon emission rights in the market is relatively low, enterprise I does not have sufficient motivation to autonomously reduce emissions and sell surplus carbon emission rights, so most of the time, the emission reduction effect of the carbon market system is inferior to the carbon tax system under this circumstance. However, when $P^* = P$, the emission reduction effect of the carbon tax system under this circumstance is the same as the carbon market system. Due to reasons such as the lower management cost of the carbon tax system than the carbon market system, the carbon tax system should be preferred at $P^* = P$.

Figure 8
Company I emission reduction scenario three



(4) When the cost of emission reductions for a company exceeds the cost of carbon taxation but remains less than the cost of purchasing carbon emission rights

Under certain circumstances, a company's cost to reduce emissions might surpass the cost of carbon taxation but still be inferior to the cost of procuring carbon emission permits. This scenario engenders two pivotal ramifications. Initially, corporations lack the incentive to procure carbon emission rights, potentially resulting in a dysfunction in the carbon trading market. Subsequently, in such a context, enterprises might be more inclined to remit the carbon tax, as it becomes a more financially prudent alternative compared to emission reductions, aiding in profit maximization. Consequently, companies might abstain from proactive emission mitigation measures, leading to a nullified reduction effect.

The significance of this outcome accentuates some potential limitations of the carbon taxation system, especially when companies are motivated to shift the cost of carbon emissions onto consumers or employ strategies to evade carbon taxes. Although the carbon taxation mechanism is conventionally deemed a dual-purpose tool – offering fiscal incentives while reducing emissions – in this instance, the emission reduction is null, lacking tangible environmental benefits. This underscores the imperative for governments to implement supplementary policy measures when adopting a carbon taxation system, ensuring companies are motivated not merely to evade the tax but to genuinely reduce carbon emissions. Scrutinizing this scenario can illuminate the constraints of the carbon tax system, particularly when it may fail to achieve anticipated emission reductions under specific market conditions.

4. Conclusion and Policy Recommendations

4.1. Conclusion and interpretation

Given the idiosyncrasies of the Chinese market, this study's model analysis, set against the backdrop of a duopolistic market, bounded rational decision-making, and inelastic price reactions, suggests that both carbon taxation and carbon trading mechanisms can achieve analogous emission reduction outcomes. Synthesizing domestic literary reviews and empirical studies permits a more nuanced exploration of the practical advantages of these systems within the Chinese context.

Initially, in China, the carbon taxation system boasts latent superiority, given its seamless integration potential within the existing taxation framework, thereby mitigating governmental administrative costs. Conversely, despite the presence of successful international precedents, the carbon trading scheme in China necessitates the establishment and maintenance of an entirely novel infrastructure and regulatory body, potentially culminating in elevated administrative expenses.

Furthermore, considering the business milieu in which Chinese enterprises operate, the carbon tax system might proffer a more stable operating environment, allowing corporations to prognosticate carbon tax costs with relative precision. The carbon trading mechanism, with its susceptibility to carbon price volatility, might accentuate operational risks for businesses within the Chinese marketplace.

Moreover, in light of China's industrial composition and sectoral distribution, the carbon taxation scheme offers a more expansive coverage, making it pertinent across a multitude of industries and sectors. In contrast, the carbon trading mechanism might exhibit a proclivity toward specific high-emission sectors, resulting in a more circumscribed scope within the Chinese market.

4.2. Limitations of this study and policy recommendations

Upon delving deeply into the Chinese market context, this paper discerns that the carbon tax system, particularly when weighing administrative costs, operational risks, market coverage, and the stability of governmental revenues, might possess manifold advantages. However, during the research process, several limitations emerged:

(1) Model Assumptions Constraint: The model assumptions, such as duopoly and bounded rationality, might not wholly resonate with China's intricate market structure.
(2) Research Methodology and Data Issues: Different regions and sectors might necessitate distinct research methodologies and data, leading to disparate conclusions.
(3) Disparities in Actual Policy Implementation: Policy enactments in various locales could influence outcomes.
(4) External Factor Impacts: Aspects like economic growth and technological innovation might sway policy outcomes.
(5) Societal Acceptance Disparities: Cultural and societal value distinctions might result in differential acceptance levels for carbon tax and carbon trading.

In light of the aforementioned constraints and market analyses, we proffer the following policy recommendations:

(1) Set carbon tax prices referencing regional market clearing prices: This would augment emission reduction efficacy in specific economic contexts.
(2) Emerging markets should prioritize the carbon tax system: Especially in locales where the market structure might exhibit oligopolistic tendencies.
(3) Refine strategies for oligopolistic markets: For extant regional carbon markets with oligopolistic characteristics, consider integration into a national carbon market or transition to a carbon tax system.

In summation, future research and policy formulation should judiciously consider these constraints and recommendations to ensure policy efficacy and adaptability.

4.3. Future directions for improvement

Future research directions in the Chinese market context include:

(1) Incorporating Supply Chain Considerations: Incorporating the impact of supply chains, as highlighted by Hu et al. (2020), can complicate but also authenticate the model within the Chinese market.
(2) Empirical Studies and China's Carbon Tax Implementation: With China's carbon tax still in its rollout phase, leveraging empirical data from this process will enhance the research's relevance and persuasiveness.
(3) Inclusion of Chinese Government's Policy Intervention: Including the Chinese government's influence in the model can make it more reflective of the actual market conditions in China.
(4) Integrating Green Finance Factors: Investigating the role of green finance, as examined by Gao et al. (2023) in their studies on economic growth and carbon emission performance in China, can provide valuable insights for the model.

(5) Expansion of Model Application: Adapting the model to different industries or regions within China, or including unique Chinese variables like the pace of technological advancement and innovation, can broaden its applicability and relevance in the Chinese context.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

References

Andreyeva, T., Long, M. W., & Brownell, K. D. (2010). The impact of food prices on consumption: A systematic review of research on the price elasticity of demand for food. *American Journal of Public Health*, *100*(2), 216–222. https://doi.org/10.2105/AJPH.2008.151415

Antimiani, A., Costantini, V., Martini, C., Salvatici, L., & Tommasino, M. C. (2013). Assessing alternative solutions to carbon leakage. *Energy Economics*, *36*, 299–311. https://doi.org/10.1016/j.eneco.2012.08.042

Antoci, A., Borghesi, S., Iannucci, G., & Sodini, M. (2021). Should I stay or should I go? Carbon leakage and ETS in an evolutionary model. *Energy Economics*, *103*, 105561. https://doi.org/10.1016/j.eneco.2021.105561

Barker, T., Junankar, S., Pollitt, H., & Summerton, P. (2007). Carbon leakage from unilateral environmental tax reforms in Europe, 1995–2005. *Energy Policy*, *35*(12), 6281–6292. https://doi.org/10.1016/j.enpol.2007.06.021

Böhringer, C., Conrad, K., & Löschel, A. (2003). Carbon taxes and joint implementation. An applied general equilibrium analysis for Germany and India. *Environmental and Resource Economics*, *24*, 49–76. https://doi.org/10.1023/A:1022849730905

Burniaux, J. M., & Oliveira Martins, J. (2012). Carbon leakages: A general equilibrium view. *Economic Theory*, *49*, 473–495. https://doi.org/10.1007/s00199-010-0598-y

Carattini, S., Carvalho, M., & Fankhauser, S. (2018). Overcoming public resistance to carbon taxes. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(5), e531. https://doi.org/10.1002/wcc.531

Chen, X. (2022). The mechanisms and comparative institutional choices of carbon emission trading and carbon taxation (in Chinese). *Fujian Forum: Humanities and Social Sciences Edition*, (1), 12.

China Energy and Environmental Policy Research Center. (2022). *China carbon market review and outlook*. Retrieved from: https://ceep.bit.edu.cn/docs/2022-01/eb3a1bf65b6e499281122c9d55ef2f7d.pdf

Chinese Academy of Fiscal Sciences. (2020). *Fiscal and tax policy reform to promote green development in the new era: Timing for carbon tax implementation, optimization of environmental protection tax, and fiscal expenditure policy evaluation (Final report)*. Retrieved from: https://www.efchina.org/Attachments/Report/report-lceg-20210207-3/

Dissou, Y., & Karnizova, L. (2016). Emissions cap or emissions tax? A multi-sector business cycle analysis. *Journal of Environmental Economics and Management, 79*, 169–188. https://doi.org/10.1016/j.jeem.2016.05.002

Ding, S., Zhang, M., & Song, Y. (2019). Exploring China's carbon emissions peak for different carbon tax scenarios. *Energy Policy*, *129*, 1245–1252. https://doi.org/10.1016/j.enpol.2019.03.037

Dong, H., Dai, H., Geng, Y., Fujita, T., Liu, Z., Xie, Y., . . . , & Tang, L. (2017). Exploring impact of carbon tax on China's CO2 reductions and provincial disparities. *Renewable and Sustainable Energy Reviews*, *77*, 596–603. https://doi.org/10.1016/j.rser.2017.04.044

Dong, M., & Li, C. (2020). The comparison and selection of realization mechanism for carbon emission reduction goals: Based on quantity-based and price-based emission reduction policy tools simulation (in Chinese). *Chinese Journal of Environmental Management*, *12*(4), 120–128. https://doi.org/10.16868/j.cnki.1674-6252.2020.04.120

Duan, Y., & Yang, C. (2017). Spatial decomposition of differences in energy consumption and CO2 emissions between China and Japan (in Chinese). *Systems Engineering Theory and Practice*, *37*(8). https://doi.org/10.12011/1000-6788(2017)08-2083-08

Eichner, T., & Pethig, R. (2011). Carbon leakage, the green paradox, and perfect future markets. *International Economic Review*, *52*(3), 767–805. https://doi.org/10.1111/j.1468-2354.2011.00649.x

Fang, L., & Tang, H. (2022). The effect of carbon emission trading on corporate carbon reduction: An analysis based on China's listed companies data using the Quasi-natural experiment method (in Chinese). *Journal of Shaanxi Normal University: Philosophy and Social Sciences Edition*, *51*(5), 14–29.

Freire-González, J. (2018). Environmental taxation and the double dividend hypothesis in CGE modelling literature: A critical review. *Journal of Policy Modeling*, *40*(1), 194–223. https://doi.org/10.1016/j.jpolmod.2017.11.002

Friedman, J. (1982). Oligopoly theory. *Handbook of Mathematical Economics*, *2*, 491–534. https://doi.org/10.1016/S1573-4382(82)02006-2

Fu, Z., Cheng, Y., Xu, W., Shi, W., & Fan, Y. (2018). Seizing the opportunity to implement carbon taxation while actively promoting carbon trading (in Chinese). *Fiscal Research*, (4), 18.

Gao, J., Hua, G., Mahamane, F., & Li, Z. (2023). Can green transformation finance contribute to urban carbon emission performance? An empirical analysis based on a spatiotemporal bi-fixed SPDM model. *Environmental Science and Pollution Research*, *30*, 102947–102971. https://doi.org/10.1007/s11356-023-29630-2

Hai, X. (2016). *Price determinants and risk measurement in the EU carbon emission quota trading market (in Chinese)*. Doctoral Dissertation, Tianjin University.

Hou, C. (2022). The impact of the launch of the national carbon emission trading market on enterprise value: Based on theoretical analysis and empirical research (in Chinese). *Wuhan Finance*, (9), 81–88.

Hu, X., Yang, Z., Sun, J., & Zhang, Y. (2020). Carbon tax or cap-and-trade: Which is more viable for Chinese remanufacturing industry? *Journal of Cleaner Production*, *243*, 118606. https://doi.org/10.1016/j.jclepro.2019.118606

Jia, X., & Wang, Z. (2021). Constructing a compound mechanism for carbon emission reduction in China under the opportunity of carbon taxation (in Chinese). *Taxation Research*, *8*, 18–21.

Jung, J., Moon, S., Yeo, S., & Lee, D. J. (2023). How would the carbon market affect the choice of input factors for production? A duopolistic model. *Energy*, *282*, 129024. https://doi.org/10.1016/j.energy.2023.129024

Kossoy, A., & Guigon, P. (2012). *State and trends of the carbon market 2012*. Retrieved from: https://policycommons.net/artifacts/1519698/state-and-trends-of-the-carbon-market-2012/2200160/

Kuang, D. (2014). *The impact of "Carbon trading-carbon tax" policy choices on China's economy and carbon emission reduction (in Chinese)*. Master's Thesis, Chongqing University.

Li, M. F., Hu, H., & Zhao, L. T. (2022). Key factors affecting carbon prices from a time-varying perspective. *Environmental Science and Pollution Research*, *29*(43), 65144–65160. https://doi.org/10.1007/s111356-022-20376-x

Li, W., & Jia, Z. (2017). Carbon tax, emission trading, or the mixed policy: Which is the most effective strategy for climate change mitigation in China? *Mitigation and Adaptation Strategies for Global Change*, *22*, 973–992. https://doi.org/10.1007/s11027-016-9710-3

Liu, L., & Zhang, Y. (2019). Research on carbon tax system based on carbon emission trading market (in Chinese). *Taxation Research, 2019*(2), 46–52. http://doi.org/10.19376/j.cnki.cn11-1011/f.2019.02.009

Liu, Q. (2022). The theoretical basis and institutional construction of carbon taxation under the "Dual carbon" targets (in Chinese). *Journal of Huazhong University of Science and Technology: Social Science Edition*, *36*(2), 108–116.

Liu, W., Li, Y., Liu, T., Liu, M., & Wei, H. (2021). How to promote low-carbon economic development? A comprehensive assessment of carbon tax policy in China. *International Journal of Environmental Research and Public Health*, *18*(20), 10699. https://doi.org/10.3390/ijerph182010699

Mao, T. (2017). Legislative ideas for carbon tax in China under the background of the Paris climate agreement (in Chinese). *Journal of China University of Political Science and Law, 43*(3), 5–9. http://doi.org10.3969/j.issn.1006-530X.2017.03.001

Markard, J. (2022). *Beyond carbon pricing: Six sustainability transition policy principles for net zero*. Retrieved from: https://eu.boell.org/en/beyond-carbon-pricing

Montgomery, W. D. (1972). Markets in licenses and efficient pollution control programs. *Journal of Economic Theory*, *5*(3), 395–418. https://doi.org/10.1016/0022-0531(72)90049-X

Pan, D., Zhang, C., Zhu, D., & Hu, S. (2023). Carbon price forecasting based on news text mining considering investor attention. *Environmental Science and Pollution Research*, *30*(11), 28704–28717. https://doi.org/10.1007/s11356-022-24186-z

Pan, Y., Hussain, J., Liang, X., & Ma, J. (2021). A duopoly game model for pricing and green technology selection under cap-and-trade scheme. *Computers & Industrial Engineering*, *153*, 107030. https://doi.org/10.1016/j.cie.2020.107030.

Shang, J. (2013). *Research on the construction of carbon emission trading mechanisms in Western China (in Chinese)*. Doctoral Dissertation, Southwest University of Finance and Economics.

Simon, H. A. (1997). *Models of bounded rationality: Empirically grounded economic reason (Vol. 3)*. USA: MIT Press.

Sun, Z. (2022). How to rationally allocate limited government regulatory resources—The rise of risk-based regulatory models and their potential operational risks (in Chinese). *Journal of Shanghai Administration Institute.* http://doi.org/10.3969/j.issn.1009-3176.2022.02.003

Tang, B. J., Ji, C. J., Hu, Y. J., Tan, J. X., & Wang, X. Y. (2020). Optimal carbon allowance price in China's carbon emission trading system: Perspective from the multi-sectoral marginal abatement cost. *Journal of Cleaner Production*, *253*, 119945. https://doi.org/10.1016/j.jclepro.2019.119945

Tian, Y. (2021). The application of financial instruments in the carbon emission trading system (in Chinese). *Value Engineering*, *40*(14), 2.

Von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior (60th Anniversary Commemorative Edition)*. USA: Princeton University Press.

Wang, H., Li, Y., & Bu, G. (2023). How carbon trading policy should be integrated with carbon tax policy—Laboratory evidence from a model of the current state of carbon pricing policy in China. *Environmental Science and Pollution Research*, *30*(9), 23851–23869. https://doi.org/10.1007/s11356-022-23787-y

Wang, X., Huang, J., & Liu, H. (2022). Can China's carbon trading policy help achieve carbon neutrality?—A study of policy effects from the five-sphere integrated plan perspective. *Journal of Environmental Management*, *305*, 114357. https://doi.org/10.1016/j.jenvman.2021.114357

Wang, Y. (2019). *A simulation study on the impact of different carbon tax collection methods on China's regional economy (in Chinese)*. Master's Thesis, Zhejiang University of Finance and Economics.

Wara, M. (2007). Is the global carbon market working? *Nature*, *445*(7128), 595–596. https://doi.org/10.1038/445595a

Wei, Q. (2015). Compatibility analysis of carbon trading and carbon tax—A discussion on China's emission reduction path (in Chinese). *China Population, Resources and Environment.* http://doi.org/10.3969/j.issn.1002-2104.2015.05.005

Wei, Y. M., Chen, K., Kang, J. N., Chen, W., Wang, X. Y., & Zhang, X. (2022). Policy and management of carbon peaking and carbon neutrality: A literature review. *Engineering*, *14*, 52–63. https://doi.org/10.1016/j.eng.2021.12.018

Wittneben, B. B. (2009). Exxon is right: Let us re-examine our choice for a cap-and-trade system over a carbon tax. *Energy Policy*, *37*(6), 2462–2464. https://doi.org/10.1016/j.enpol.2009.01.029

World Bank. (2021). *State and trends of carbon pricing 2021*. Retrieved from: http://hdl.handle.net/10986/35620

Wu, L., Qian, H., & Tang, W. (2014). Carbon emissions trading and carbon tax choice mechanism based on dynamic marginal abatement cost simulation (in Chinese). *Economic Research*, *49*(9). http://doi.org/CNKI:SUN:JJYJ.0.2014-09-004

Xu, P. (2022). *Industrial green transformation, financial policies, and macroeconomic fluctuations (in Chinese)*. PhD Thesis, Nankai University.

Xu, T., Kang, C., & Zhang, H. (2022). China's efforts towards carbon neutrality: Does energy-saving and emission-reduction policy mitigate carbon emissions? *Journal of Environmental Management*, *316*, 115286. https://doi.org/10.1016/j.jenvman.2022.115286.

Yang, C., Tian, Y., & Xu, X. (2021). Pathways to achieve carbon peaking and carbon neutrality through price and tax mechanisms (in Chinese). *Price Theory and Practice*. https://doi.org/10.19851/j.cnki.CN11-1010/F.2021.01.22

Yang, L. (2023). *Legal issues in China's carbon emission trading system (in Chinese)*. Doctoral Dissertation, Northwest Minzu University.

Yang, Y. (2013). The theory of externalities and internalization pathways of carbon emissions (in Chinese). *Productivity Research*. https://doi.org/CNKI:SUN:SCLY.0.2013-12-021

Yao, X., Huang, R., & Song, M. (2019). How to reduce carbon emissions of small and medium enterprises (SMEs) by knowledge sharing in China. *Production Planning & Control*, *30*(10–12), 881–892. https://doi.org/10.1080/09537287.2019.1582096.

Zhang, Z. (2022). What does the establishment of a unified national market mean for the development of the national carbon market? (in Chinese). *Economic Research Reference*.

Zhu, J., & Sun, L. (2022). Did carbon emission trading policies improve China's total factor energy efficiency? (in Chinese). *Modern Economic Exploration*.

How to Cite: Chang, Y. (2023). Duopoly with Limited Rationality in Carbon Market: A Comparison of Carbon Quota Trading and Carbon Tax System. *Green and Low-Carbon Economy* https://doi.org/10.47852/bonviewGLCE32021618