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# Application of Game Theory in Carbon Trading Mechanism

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**ABSTRACT**
This paper organized the literature about the allocation of game theory in carbon emission trading by consulting relevant research of peer scholars. As a result, we found that the total amount of newly published papers about carbon trading has declined in recent years while the number of new papers about game theory is steadily increasing in the last decade, and there has been an unprecedented enthusiasm among Chinese scholars to research emission trading system (ETS). Furthermore, when it comes to specific core themes of studies, more than half of the literatures concentrated on the perspective of government, about one-third of the literatures emphasized the perspective of enterprises, and only less than ten per cent of literatures focused on the coordination between government and enterprises. By such a method, this study clarified the tendency of relevant research in the past decade. It came up with a general analysis about the application of game theory in carbon trading mechanisms. According to the analysis, we anticipated that research about game models of carbon trading between different countries or economies would be an extraordinarily valuable direction in the upcoming period.

***Keywords:*** *Game theory, Carbon trading, Economic model, Marginal analysis*

## 1. INTRODUCTION

### *1.1. Research Background*

In general, greenhouse gases are the main gases responsible for the greenhouse effect, including carbon dioxide, methane, nitrous oxide. To illustrate, carbon dioxide has the function of heat absorption and heat insulation. Excessive carbon dioxide will form an invisible glass cover on the earth's surface so that the heat radiated by the sun to the earth cannot be radiated to outer space, increasing the temperature of the earth's surface. Therefore, carbon dioxide is defined as a greenhouse gas. Since the first industrial revolution in the 1760s, carbon dioxide emissions have been increasing with the development of the global manufacturing industry. The decision-makers of the fourth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) report by the first working group have pointed out that the correlation between human activities and climate changes in the past half-century has reached 90%. Undoubtedly, a stable and suitable climate is necessary for both survival of natural organisms and the economic and social development of the human being. Unfortunately, global warming will result in a series of natural imbalances, such as melting of glaciers, rising sea levels, and frequent extreme weather, some of which have already occurred. These changes in the natural environment will definitely generate a negative impact on modern society of humanity, causing economic losses and even survival threats. In this sense, reducing greenhouse gas emissions is not only to protect the environment but also to protect human beings by guaranteeing a necessary and sufficient condition for sustainable economic and social development. Therefore, it is urgent to reduce the emission of greenhouse gas, especially emissions of carbon dioxide, while trying to maintain the negative effect upon the manufacturing industry and economic development as little as possible. The government can reduce emissions through two major policy tools: carbon tax and carbon trading.

 

### *1.2. Research Significance*

In comparison, carbon trading has a higher public participation rate and the ability to present the effect of greenhouse gas emission reduction more intuitively and concretely. In addition, carbon trading can also encourage developing countries to reduce carbon emissions by project emission reduction and carbon offset, leading to a wider scope of application on a global scale. Therefore, correctly building and operating an efficient carbon trading system has become a powerful driving force for the sustainable low-carbon development of enterprises and countries, so this paper will focus on carbon trading. To generate a helpful proposal on such an issue, this study will review references to analyze how all kinds of game models are employed in carbon trading mechanisms. Based on the analysis, we will be able to find out the merits and deficiencies of these models and develop new orientations in this field.

Overall, there are three different applications of game theory in carbon trading: the balance between carbon reduction and economic development, the game among countries on a global scale, and the game among enterprises in the carbon trading market. Specifically, the first two kinds of applications are often analyzed on the global market, which is based on economic theory and driven by political issues and international relationships. In contrast, the games among enterprises usually operate in the domestic market, and the trading mechanism is more consistent with the model of game theory in the microeconomic domain. Under such circumstances, this paper will cover all kinds of applications of game theory but employ more length focusing on game theory in the domestic carbon trading system. Various policies are implemented by different economies, including developed countries, developing countries, and regional unions when it comes to carbon trading. Thus, we will compare carbon trading mechanisms applied by the typical representation of different economies (i.e., Japan, China, and the European Union) and list the relative merits of these applications. In specific, this paper will consist of three parts: introduction, reference review about the employment of game theory in emission trading system (ETS), and discussions and conclusions about references.

## 2. LITERATURE REVIEW

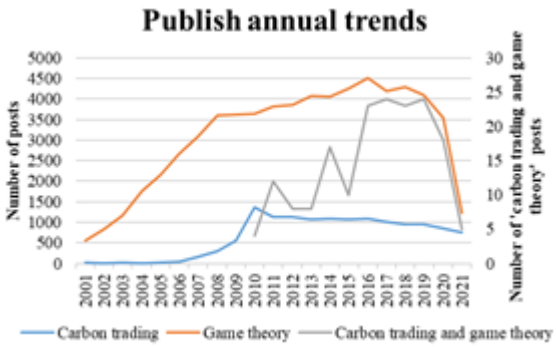


**Figure 1.** Trend chart of the volume of articles published on themes from 2001 to 2021

There are 13,656 articles related to carbon trading in the past 20 years. The number of articles published began to grow rapidly in 2006, peaked in 2010, and then decreased year by year. It can be seen that the carbon trading boom is gradually shrinking. There have been 65,072 academic articles related to game theory in the past 20 years. The number of articles published has grown rapidly since 2000 and entered a stage of steady growth in 2008. The average number of new papers published in the past ten years has exceeded 4000 times, which shows that game theory is a hot research topic at the moment.

In terms of the total number of academic articles, which is less than 25 academic articles per year, that combine game theory and carbon trading, the number of publications is small, which means that the number of researchers is small and there is more research space. With the rise of game theory and many remaining problems of carbon trading, the application of game theory to solve the problems in carbon trading and promote the development of carbon trading has a very important and positive effect on social and economic development.

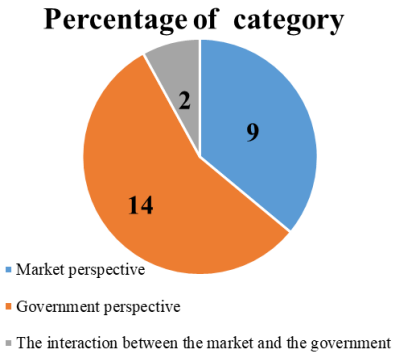


**Figure 2.** Distribution of sample topics

This review selected 25 articles with larger impact factors from the database for literature review. Among them, 9 articles mainly emphasized the market, accounting for 36% of the total length; 14 articles

mainly focused on the government's perspective, accounting for 56% of the total; only 2 articles focused on the interaction and influence between the government and enterprises, accounting for 8 %.

### *2.1. Market Perspective*

The EU trading system is the most representative carbon trading system. Shaochen uses literature research, quantitative and qualitative analysis to study its problems. Studies have shown that reforms that change the supply side of the trading system and the flexibility of the system can help promote the smooth operation of the market [1]. Numerous studies have shown that the marginal cost of abatement is a significant factor influencing the choice of a company's emission reduction activities. Tu Jianming, Li Xiaoyu and Guo Zhangcui tried to incorporate corporate budgets into the comprehensive budget system to guide corporate rational carbon emission reduction activities. By quantifying the carbon emissions of enterprises, they mapped the enterprise's comprehensive budget preparation process embedded in the carbon budget and the enterprise's carbon emission trading budget table [2]. Jialin and her colleagues analyzed the emission reduction behavior in carbon emissions. They established a corresponding evolutionary game model based on the assumption of incomplete information and the idea of "replication dynamics". In specific, the carbon quota would be distributed in various ways in response to different conditions. According to the calculation result, the enterprise's emission reduction strategy depends on comparing the unit emission reduction cost [3]. Fu Jingyan and Dai Yuting studied the cost and welfare changes of the carbon trading market. They use carbon intensity as an indicator to measure the difference in technological level between regions, fit the marginal abatement cost curve. The research shows that the regional heterogeneity measured by carbon intensity will lead to the differentiation of the MAC curve. The establishment of a unified carbon trading market can reduce the transaction cost of traders and improve the efficiency of the carbon trading market [4]. Wu Libo and his colleagues studied their carbon emission trading and carbon tax policy choices for greenhouse gas emission control. They constructed a multi-regional dynamic general equilibrium model in China, simulated and analyzed the marginal abatement cost curve. They found that the slope of the marginal abatement cost curve gradually increases with the advancement of emission reduction actions. [5]. Feng Nan has studied the operating mechanism of the international carbon finance market. She analyzes the operating mechanism of the international carbon financial market in a low-carbon economy through the establishment of models, mathematical derivation and logical reasoning. Studies have shown that emission companies can choose to purchase emission rights through market transactions or increase investment in emission reduction technologies to achieve their own emission reductions. The boundary of a company's strategic choice lies in balancing the marginal emission reduction cost and the marginal emission benefit [6]. To test whether the emission trading mechanism is still effective in China, Hu Jun and his colleagues built an econometric model to examine the impact of market-incentive carbon emission trading mechanism on the technological innovation of Chinese enterprises. The results show that implementing the carbon emission trading mechanism has a significant role in promoting the technological innovation of enterprises [7]. Juanjuan and her colleagues investigated the value of advance payment financing to carbon emission reduction by analyzing two models: a supply chain model with a manufacturer that is not capital-constrained and a supply chain model with a capital-constrained manufacturer. The calculation results show that the retailer's optimal profit would increase consistent with the efficiency of carbon emission reduction and consumers' low carbon awareness when the price discount is low [8]. Carbon reduction cooperation among enterprises is also a very important theme. Wang Kai and his colleagues proposed a new incentive model that was developed to consider the carbon emission intensity of enterprises and cooperative game theory. According to the result of the cooperative model, after adjusting quota by the carbon emission intensity, enterprises with low carbon emission intensity would get more quotas. The income of quota trading would exceed the cost of energy-saving technology, which means that these enterprises can continue to produce under the fairer premise and ensure the sustainability of emission reduction [9].

### *2.2. Government Perspective*

#### *2.2.1. Domestic*

Research proves that government policies affect carbon emission reduction activities. Huang Xianglan and his colleagues have used the difference-differences model to analyze the environmental dividend. They found that China's carbon emissions trading policy contributes to the realization of environmental dividends [10]. As for Japan, Andrew and his colleagues built an ETS model in which each prefecture could strategically trade carbon emission allowances with other prefectures and maximize profitability. According to game theory, both parties to the transaction can achieve ROI within 20 years under reasonable carbon pricing regimes [11]. Many scholars have put forward policy suggestions on how the government can intervene in the environmental economy. Tang Yuejun and Li Defu have built a theoretical model based on the discussion of environmental capital and negative externalities. According to the model's simulation results, they suggest that the government should define the initial

property rights of environmental resources and establish an environmental energy trading market to guide carbon emission rights trading [12]. In addition, Li Xiaosheng and Song Malin used the DEA model of centralized allocation "zero-sum game" to calculate the initial allocation of carbon emissions in China. They found that the carbon emission quotas of provinces with higher efficiency should be increased in terms of space allocation. Measured by the DEA model, the government should formulate policies in accordance with the principle of efficient distribution [13]. Kourosh and Ashkan applied a Stackelberg game model between the government and a multi-stage GSC (Green Supply Chain). They found that inventory decisions influence the carbon emission of the GSC, while operational adjustment can be an effective way for carbon reduction. In addition, the inventory cost and the carbon emission of the GSC have inverse relations, which means the government can trade off the costs and carbon emissions by setting appropriate regulations and parameters [14]. Moreover, Some scholars formulated the policy game into a Stackelberg model with two sub-models, developing a hybrid algorithm that combined a polynomial dynamic programming (PDP), Cournot competition, and genetic algorithm (GA) to solve the game model. Since the corresponding tight/easy regulation policies significantly influence the emission reduction results, including social welfare, actual emissions, and total costs, they suggest that the government should be very careful when deciding on the emission reduction target and setting its preference on the environmental utility [15]. Wanting and Zhihua developed a model of evolutionary game theory about the interaction between governments. According to the model, various carbon taxes and subsidies generate different probabilities that manufacturers will produce low-carbon products. They suggest that governments should gain an advantage by implementing either dynamic taxes or static subsidies, static taxes and dynamic subsidies [16]. In addition, some scholars employed the marginal analysis method to compare carbon trading based on number control and carbon tax based on price control. By comparing the marginal cost & benefit curve, they suggest that the policy combination of the carbon tax in the short term should be consistent with carbon trading in the long term [17]. On the other hand, some scholars employed evolutionary game theory to model and analyzed the evolutionary process of bounded rational game agents. According to the result of game analysis, the "one-size-fits-all" penalty multiplier currently adopted in China's carbon market is inapplicable to the building sector, and non-financial incentive measures cannot fundamentally alter the owner's behavior [18].

### *2.2.2. International*

Research shows that international carbon trading cooperation has a positive effect on economic development. Based on the fact that firms located in different countries have different efficiency in carbon reduction, Shihui and Shoudao constructed a two-stage model about the government's choice of environmental policies and firms' abatement strategy. According to the Nash equilibria, both countries could provide welfare by choosing carbon emission trading policies, which would be the optimal combination of policies under certain situations [19]. In addition, Ji Ming established a signaling game model for the greenhouse gas emission supervision mechanism. The research results show that in the state of separation equilibrium, the two parties of the game can obtain the truest and effective information transmission, thus forming the most efficient equilibrium state of the signal transmission game [20]. There are many studies on how different countries can cooperate in carbon trading. Jing Kedi used the game theory method to model the carbon emission reduction cooperation between countries and provided China with the best strategy in the international carbon negotiation game [21]. Zhang Yutai and his colleagues have studied the international carbon emissions trading system. They conducted a fair initial allocation of global carbon emission budgets among different countries based on the principle of equal per capita and mathematical calculations of the currently available budgets in national accounts. They suggest that developed countries must raise budgets for their emissions by buying quotas or transferring advanced technologies in exchange for quotas since the accounts of developed countries are already in deficit [22]. Research shows that the government's carbon emission reduction policies need to be adapted to local conditions. Mengya and her colleagues compared the mechanisms of emission trading schemes (ETS) in the European Union with those in China by adopting 8 mechanisms as comparative indicators and designing 19 sub-indicators. They found that imitation and blind copying would lead to a situation of non-acclimatization, failure of ETS, and a considerable loss of manpower and resources. Therefore, governors must improve and perfect legal systems by implementing separate national-level regulations for allowance allocation, MRV, and adding stipulations for provincial cooperation and allowing provinces to develop local ETS [23].

## *2.3. Interaction Between the Market and the Government*

Research shows that governments and companies can cooperate and win-win on carbon trading issues. Xia Liangjie studied the three-stage game of "carbon emission rights allocation-emission reduction research and development decision-output decision" between the government and duopoly enterprises that produce

homogeneous products. The study found that compared with emission reduction competition, the social welfare, output and emission reduction of enterprises in cooperation in emission reduction are greater [24]. In addition, some scholars constructed a game model including governments' subsidy policies, manufacturers' environmental quality measures, and customer environmental awareness (CEA). According to the Nash equilibria of the government and manufacturers, increasing penalties and CEA would be beneficial for both government and enterprises and presented a win-win situation. Improving the environmental quality of ESPs could increase manufacturer integrity, and the government's inspection cost is critical to manufacturers' decisions [25].

## 3. CONCLUSION

In this paper, we organized the literature about the allocation of game theory in carbon emission trading by consulting relevant research of peer scholars. According to the literature review, as global warming and climate change have become one of the most significant issues on a global scale, there are plenty of literatures about this subject being published in recent years. In particular, there has been an unprecedented enthusiasm among Chinese scholars in which scholars from various institutions all conduct research studies about the intersection between game theory and emission trading system (ETS). When it comes to specific core themes of literatures, the total amount of newly published papers about carbon trading has declined in recent years, while the number of new papers about game theory is steadily increasing in the last decade, which generates a lot of inspiration for this paper.

Firstly, we found that majority of literatures concentrated on the perspective of government (i.e., 56% of reviewed literatures). In specific, there are two subfields under this topic: domestic mechanism and international mechanism. On the one hand, official policies implemented by the government could significantly affect the effect of carbon emission reduction. Still, the efficiency of various policies might be quite different, which means the government's emission reduction policy needs to be flexible based on the consistency of game theory and local economic development. On the other hand, initial allocation is important for the carbon trading game between countries. The different roles played by developing economies (e.g., EU) and economies (e.g., China) must be considered with the development of the global market. In addition, about one third (i.e., 36%) of the reviewed papers emphasized the perspective of enterprises. According to the research result of ETS in different economies, the marginal emission reduction cost of enterprises is a significant factor that affects the choice of emission reduction activities, which means carbon quota is supposed to be distributed in carbon in the trading market in response to different conditions of enterprises. Furthermore, only 8% of reviewed papers discussed the coordination between government and enterprises. Based on analysis of the literatures, we found that increment in penalties would be beneficial for both government and enterprises and presented a Nash equilibrium in game model, which could increase the welfare of all kinds of stakeholders. To sum up, we constructed this literature review in response to the increasingly crucial issue about the employment of game theory in carbon trading mechanisms by organizing literatures based on different perspectives. In this sense, this paper clarified the tendency of relevant research in recent years and generated constructive analysis about the application of the various game model in ETS. Since globalization has coincided with climate change in an unprecedented pattern, we believe that research about the carbon trading game between different countries or economies would be an extraordinarily valuable direction in the future.

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