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"Gheorghe Asachi" Technical University of Iasi, Romania

POLLUTION RIGHTS TRADING: A STUDY BASED ON THE QUOTATION SYSTEM OF MARKET MAKERS

Aiqin Zhou[1], Yusen Zhou[2*], Lifeng Li[3], Dapeng Wang[3], Qinghua Li[3]

[1]*Aiqin Zhou Shandong University of Finance and Economics School of Business Administration, 25000. china*
[2]*Neoma Business School, Mont Saint Aignan Cedex 76825, France*
[3]*School of Economics and Management, Beijing Jiaotong University Beijing 10044, China*

Abstract

Pollution control is vital for human beings to create a harmonious living environment, and it is an important challenge for all countries worldwide. The emissions trading applicability in the market maker system can play an important role in the process of pollution control. To evaluate the effectiveness of the quotation trading system, it is necessary to develop a system strategy for market makers in emissions trading. In this paper, first the mechanism of the formation of the best offer to market makers is studied based on the construction of the three players' dynamic game model. Then, we construct the system cost model of the market maker quotation transaction by comparing the system costs of the market maker. Finally, this paper provides a set of incentives and constraints to guarantee the quotation trading of market makers, including policy recommendations for the implementation of the quotation trading system of market makers etc.

Key words: emissions rights pricing, emissions trading, market maker

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1. Introduction

Although China has conducted emissions trading work for almost 30 years, the implementation of the transactions is not satisfactory. According to the statistics of the *Ministry of Environmental Protection*, the pollutant emissions situation is still too serious, but the reason why the inactive nature of the emissions trading market is imperfect is not clear yet, and the construction of the emissions trading market still has a long way to go. This situation is reflected some of the following aspects.

(1) The construction of the emissions trading centers is not perfect. The emissions trading centers are the core of the emissions trading market, which is the key to determining the efficiency of the trading market. Currently, China's emissions trading centers can be divided into three types according to their different natures, including administrative units, institutions and enterprises, but they require a coordination mechanism to work together.

(2) Insufficient innovation in the pollutant trading methods. Currently, the main targets of emissions trading in the domestic market are sulfur dioxide (SO_2), nitrogen oxides, chemical oxygen demand (COD), and ammonia nitrogen, all of which are harmful to the environment. Among these targets, sulfur dioxide (SO_2) and nitrogen oxide are air pollutants, and chemical oxygen demand (COD) and ammonia nitrogen are water pollutants. In addition, the actual waste that is discharged by companies usually contains more than one pollutant.

(3) The trading of emissions rights is inflexible. Currently, the pilot trading system in China mostly uses the bid trading mode. The core content of the bid trading mode is that polluters submit entrustment

* Author to whom all correspondence should be addressed: e-mail: qiuying@bipt.edu.cn, gb023@126.com; Phone: +86 18611895693; Fax: +86 01060228012

orders to the trading center, which collects all the entrustment orders and conducts trades according to the principles of price priority and time priority. The bidding transaction process generally needs to release sale information and implement two trading steps in the information system. Although the market transparency of bid trading is relatively high, its greatest disadvantage is that it is not conducive to the smooth completion of bulk transactions, and the market liquidity and stability are poor.

(4) Higher transaction costs in emissions trading. The transaction costs will offset the profits from emissions trading, making the trading unprofitable. Therefore, transaction costs are an important factor restricting emissions trading activities. Under the current environment, the transaction costs of emissions rights mainly include transaction management fees, transaction information search costs and transaction negotiation costs.

(5) Weak supervision of emissions trading. The regulation of trading, especially post-trading regulation, is closely related to the normal operations of the emission trading system, and it also ensures the effective implementation of emissions trading and the total volume control, which is also the focus of the government's work. Nevertheless, in practice, due to technical reasons and government regulatory failures, there are many regulatory loopholes, which may leave enterprises with illegal emissions.

Therefore, to improve the liquidity of the emissions trading market, it is necessary to revolutionize the current pollutant trading methods. In the new trading method that we developed; the market functions of the emissions trading centers should be more prominent. For example, the emissions trading centers can determine the trading equivalents of different pollutants, different pollution sources and different regions, which will expand the scope of tradable enterprises, achieve cross-type and cross-regional trading of pollutant discharge rights, liberate government functions, strengthen pollution regulations, and so on. Based on these considerations, this study proposes countermeasures for market makers to solve the liquidity dilemma of the trading market at the trading subject and trading system levels.

2. Literature review

2.1. Studies on the market maker system in emissions trading

There are two items that drive the price in the trading market: the instructions that are driven by collective bidding and the quotations that are driven by the market maker system. Under the market maker trading system, market makers are not only the direct participants in trading but also the market organizers. Market makers create trading opportunities and organize market activities.

The bid price driven market is more transparent than the order driven market. Hanousek and Podpiera (2004) studied the evolution of the Prague stock exchange after the introduction of a market maker trading system, and they found that the new system not only successfully increased the trading transparency but also enhanced the trading price discovery, which allowed traders to benefit from the reduced spreads. Venkataraman and Waisburd (2007) found that after the introduction of market maker formulation (DDM) in the Paris stock exchange, the liquidity of sample stocks through collective bidding was enhanced. Zhu et al. (2009) found that the bilateral quotation spread decreased, and the market trading volume and liquidity increased. Perotti and Rindi (2010) studied the data of sample companies and found that the act of appointing market makers as information providers reduced the spread and volatility of prices, the potential for insider trading, and the costs of adverse selection. Smeulders et al. (2019) showed that compared with pure limit orders, the mixed market structure could provide better liquidity. Weissensteiner (2019) compared the mixed market structure with pure market maker trading, and found that some indicators (trading costs, price differences and other indicators) significantly decreased.

From the perspective of the market makers' monopoly and the competition's influence on the market, Miao (2006) thought that in the New York stock exchange, the monopolistic expert system partly internalizes the externalities of the price differences in the decentralized market, thus enabling market makers to improve social welfare. In addition, some studies are carried out with respect to market stability, the financing forms of the market makers and the rationality of the market makers (Gong et al., 2019). Zhu et al. (2009) used the financial market model to test the stabilizing effect of market makers on the market. These authors assumed that there were two types of investors in the market: fundamental investors and trend investors. Chu et al. (2018) studied that the information advantages of local market makers are a very valuable factor in reducing transaction costs.

From studying the effects of market makers' quotation behavior on market efficiency, it is found that market information is an important factor that affects market efficiency (Gong et al., 2018). Germain et al. (2004) concluded that when the marketer has complete information, the equilibrium price of emission rights is consistent with the market in a Walrasian market. When the marketer does not have complete information, the marketer establishes a positive matching incentive and constraint system. Therefore, this and other studies cannot propose theoretical feasible suggestions for the adoption of a market maker system in China's emissions market.

In general, domestic and foreign studies on the market maker system of emissions trading are still far from perfect. The emissions trading market should play an active role in pollution control and constantly improve the market mechanism. The market makers are an important part of the micro market structure as an emissions trading intermediary. If market makers are introduced into the pilot stage of trading in China, the most urgent task is to have a complete system of incentives and constraints for market makers' trading to ensure the effectiveness of market makers' behaviors.

2.2. Studies on emission rights pricing

The emissions trading market includes the primary market and secondary market. After determining the total emissions rights, the government needs to allocate the total amount to the existing enterprises through the primary market to form the initial emissions rights of the enterprises. Liao et al. (2009) believed that the important factors affecting the performance of the emissions rights market include a reasonable initial distribution of the emissions rights, a trading system and a scientific and reasonable pricing mechanism for emissions rights, which will largely determine the total market volume and degree of activity of emissions rights trading. Dhingra and Morrow (2019) believed that if an enterprise had dominant market power in the emissions rights market, the initial distribution would affect the monopolistic behavior and the efficiency of the market.

In terms of auction methods, Goeree et al., (2010) experimentally studied the allocation of initial emissions rights using an auction rather than free allocation. In theory, spot market trading can eliminate the inefficiencies that are caused by initial allocation problems. In the experiment, the high emitters acted as market forces in the spot market, and the high emitters remained distorted under the free distribution.

In the secondary market, the emissions trading price system helps the pricing in the initial allocation and the pricing of the government reserve emissions rights. Fischer (2008) analyzed the relationship between environmental policy and R&D (Research and development) externalities and the relationship between innovation benefits and emissions rights prices. Liao et al. (2009) believed that the shadow price could be used as the equilibrium price, but marginal analysis could not be used in discrete optimization analysis, such as mixed integer programming. Chu et al. (2019) developed a stochastic equilibrium model to analyze the dynamic behavior of the spot price of CO_2 emissions quotas.

To sum up, the operation mode of emissions trading under the quotation trading system of market makers, including the initial distribution mode of emissions rights and the secondary market trading mode of emissions rights, will play an important role in the process of pollution rights trading. This paper analyzes the optimization of the emissions trading efficiency of the market-making quotation trading system, including the initial emissions rights allocation, the emissions trading processes, the emissions information costs, and the post trade supervision and voluntary governance of enterprises. On this basis, the paper discusses the three-player game model and the system costs model in the quotation transactions of market makers. This paper describes the trading behavior of market makers and polluters in the market by constructing a three-player dynamic game model with the quotations of market makers as the core and studies the formation mechanism of the optimal quotations of market makers and the formation mechanism of the price differences in the short term. By constructing the system costs model of quotation trading, the paper analyzes the system costs of quotation trading and the implementation conditions of the system.

3. Model analysis

According to Wang (2018), the research constructed a theoretical model for market maker's quotation trading to study the forming mechanism of the market maker's optimal quotation; while it lacks practical meaning, and people cannot understand the actual meaning of the model. This paper will discuss the incentives and constraints to guarantee the quotation trading of market makers with the simulation tool.

3.1. Variable definitions

(1) P_a is the ask price that is quoted by the market maker.

(2) P_b is the bid price that is quoted by the market maker. The difference between the ask price and the bid price, $DP = P_a - P_b$ is called the spread.

(3) $I_m(q)$are the information costs that are paid by the market maker for the pollutant discharge certificate with the trading quantity q. It should be clear that the information that is mentioned to in this paper mainly refers to the pollution control cost information of polluters, which is different from the definition of the information costs of the market makers in financial markets by researchers (Calcagno and Lovo, 2006). According to hypotheses 1 and 2, trading enterprises, as price receivers, can adjust the amount of pollution treatment to cope with changes in market prices. We consider that pollution control costs are the main influencing factor of pollution control quantity, which are also the private information of trading enterprises. Therefore, market makers should first investigate the pollution control technology level of polluters when making price decisions. To make the model lose generality, let $I_m(q)=F_M+V_M(q)$, where F_M represents the fixed costs that are paid for obtaining information, $V_M(q)$ represents the variable costs, and the formula satisfies $I_M(q)=V_M(q)>0$ and $V_M(q)>0$. Therefore, the information cost function is convex, which means that the marginal information costs increase as the trading volume increases.

The transaction enterprise behavior variable is defined as follows.

(1) N is the number of polluters participating in trading in the market. $N=N_1+N_2$ indicates that the pollutant discharge enterprise is composed of N_1suppliers and N_2 demanders. For clarity, let $i=1,2, 3\ldots N_1$ represent the sequence of enterprises that are supplying pollutant discharge certificates; let $j=1,2, 3\ldots N_j$ represent the sequence of enterprises that

demand pollutant discharge certificates; and let$j=1,2,3\ldots N_k$ represent the sequence of pollutant discharging enterprises.

(2) Q_k^0 is the initial allocation quantity of pollutant discharge certificates of pollutant discharge enterprise *k*.

(3) Q_k is the amount of pollutants that are discharged by pollutant discharging enterprise *k* at the end of the period. According to hypothesis 2, the pollutant discharge amount should be equal to the allocated amount, which establishes the relationship. $\sum_{i=1}^{N1} Q_i + \sum_{j=1}^{N2} Q_j = \sum_{i=1}^{N1} Q_i{}^0 + \sum_{j=1}^{N2} Q_j{}^0$

For enterprises selling pollutant discharge certificates, inequality$Q_i\text{-}Q_i^0<0$ is established; and for enterprises that purchase emissions certificates, inequality $Q_i\text{-}Q_i^0<0$is established.

(4) $C_k(Q_k)$is the pollution treatment cost when the pollutant discharge volume of pollutant discharging enterprise *k* is Q_k. When dealing with a small amount of pollutants, the costs for the enterprise are relatively low, but when dealing with a large number of pollutants, it is necessary to invest a large amount of capital or adopt advanced pollution control technology to upgrade the equipment. This large investment will increase the marginal costs of pollution control as the amount of sewage is reduced so that conditions $C_k(Q_k)<0$ and $C_k(Q_k)>0$ can be satisfied.

(5) $I_k(q)$is the information costs that are paid for pollutant discharge certificates (i.e., the pollutant discharge enterprise is *k* and the transaction quantity is *q* in the bidding market without market makers. Assume that a different firm *A* has the same information cost function.

To keep the model general, the variable can be expressed as $I_k(q)=F_{UM}+V_{UM}(q)$. In the formula, F_{UM} represents the fixed costs that are paid for information work, $V_{UM}(q)$ represents the variable costs, and $I_k(q)=V_{UM}(q)>0$ and $V_{UM}(q)>0$ represent that the marginal information costs increase as the trading volume increases. Compared with the quotation market with the market maker, the formula satisfies $F_{UM}<F_M$ and $I_k(q)>V_{UM}(q)$ for any polluter. The reason is that compared with polluters, market makers are willing to pay higher fixed costs for trading information due to the needs of specialized trading, but their marginal costs will be lower than polluters due to the scale effect.

3.2 Dynamic game model

3.2.1 Basic model

Market makers need to consider the impact of the quoted price on the trading volume when setting the bid price P_b and the ask price P_a. Because of the inverse relationship between the volume and price, a strategy of simply widening spreads can backfire. Therefore, rational market makers should first define the reaction function of polluters to prices. However, factors such as the governance costs that constitute the response function belong to the private information of polluters, and market makers need to pay information costs to understand private information. Therefore, the objective function of market makers should be composed of three decision variables: the quotation, the trading volume and the information cost. This function is expressed in Eq. (1).

$$Max\pi_m = P_a \sum_{j=1}^{N2} [Q_j P_a - Q_j{}^0] - P_b \sum_{i=1}^{N1} [Q_i{}^0 - Q_i P_b] - I_m(TQ) \quad (1)$$

where:

$\sum_{j=1}^{N2}[Q_j P_a - Q_j{}^0]$ is the total number of pollutant discharge certificates that are sold by the market maker, which is equal to the total number of pollutant discharge certificates that are purchased by the enterprise ($Q_j(P_a)\text{-}Q_j^0>0$) that demands pollutant discharge certificates.

$\sum_{i=1}^{N1}[Q_i{}^0 - Q_i P_b]$ is the total number of pollutant discharge certificates that are purchased by the market maker, which is equal to the total number of pollutant discharge certificates that are sold by the supplier ($Q_i^0\text{-}Q_i(P_b)>0$).$I_m(TQ)$is the information costs that are paid by market makers for trading pollutant discharge warrants (the sum of the number purchased and sold). Since the total trading volume of pollutant discharge warrants is:

$$TQ = \sum_{j=1}^{N2}[Q_j P_a - Q_j{}^0] + \sum_{i=1}^{N1}[Q_i{}^0 - Q_i P_b],$$

it can also be expressed as:

$$I_m(TQ) = I_m \sum_{j=1}^{N2}[Q_j P_a - Q_j{}^0] + \sum_{i=1}^{N1}[Q_i{}^0 - Q_i P_b]$$

Due to the existence of market makers, the game between polluters will evolve into a three-player game among demanders, suppliers and market makers. To maximize their own interests, the pricing strategy of market makers should meet the interests of trading enterprises (that is, the optimal decision of market makers should be based on the optimal decision of polluting enterprises). According to the above analysis, the constraint conditions of the model are functional Eqs. (2-4).

$$\underset{\{Q_j\}}{MinTC_j} = C_j(Q_j) + P_a(Q_j - Q_j{}^0) \quad (2)$$

$$\underset{\{Q_i\}}{MinTC_i} = C_i(Q_i) - P_b(Q_i{}^0 - Q_i) \quad (3)$$

$$\sum_{j=1}^{N2}[Q_j P_a - Q_j{}^0] + \sum_{i=1}^{N1}[Q_i{}^0 - Q_i P_b] \quad (4)$$

Constraint condition (2) represents the objective function of the enterprise that needs the pollutant discharge certificate, and constraint condition (3) represents the objective function of the enterprise that supplies the pollutant discharge certificate. Although polluters are price takers, they can optimize their cost structure by adjusting the amount of pollution that is discharged. Since price information is open and transparent in the market quotation market of market makers, trading enterprises do not need to pay information costs. The objective function of demand enterprise *j* and supply enterprise *i* is the function of the pollution treatment costs and trading volume. Functional formula (4) ensures that the numbers of pollution discharge warrants that are purchased and sold are equal, and it meets the conditions that are set by hypothesis 2. In addition, the decision variables are not less than zero.

For the above game process, the constraint condition in the model includes the objective function, and the current typical solution method is the inverse method. The inverse method is also used in this paper. First, the decision-making behavior of polluters is analyzed, and the response function of polluters is calculated. Then, the optimal bidding decision of market makers is analyzed according to the optimal decision-making behavior of polluters.

3.2.2. The optimal quotation strategy of market makers

According to the objective functions, the first-order conditions for the cost optimization of trading enterprises are $C_i(Q_j) = -P_a$ and $C_i(Q_i) = -P_b$, respectively. That is, under the condition of a given license price, polluters will adjust the emissions volume until the marginal pollution treatment costs are equal to the price, which is consistent with the research of Hahn (1984). Furthermore, the amount of sewage that is discharged is the reaction function of price. If the amounts of sewage that are discharged are defined as $Q_j(P_a)$ and $Q_i(P_b)$, respectively, the first-order conditions all meet $Q_j(P_a)<0$ and $Q_j(P_a)<0$, respectively, because when the ask price is higher, the demand for sewage permits by enterprises will be lower, and the number of sewage permits will limit the demand for pollution, resulting in the allowable amount of pollution also being less. When bid price is higher, enterprises will be allowed to sell more pollution permits, supplying enterprises will be able to increase their management amounts, and the amount of discharged pollution accordingly can be less. To make the research conclusion more concise and clearer, this paper assumes a linear relationship between the trading volume and price, and according to the first-order condition of cost optimization, the response relationship between the selling volume and price is Eq. (5).

$$Q_i^0-Q_i(P_b) = - Q_i^0 P_b/Ci(0) \tag{5}$$

In Eq. (5), the value range of the supply price satisfies $P_b \in [0, -C_i(0)]$. When the supply price is equal to $P_b=0$, the quantity that is sold is 0. When the supply price is equal to $P_b = -C_i(0)$, the supply reaches the maximum value of Q_i^0. The response relation between the purchase quantity and the price is shown in Eq. (6).

$$Q_j P_a - Q_j{}^0 = \frac{Q_j(0) - Q_j{}^0}{C_j{}'(0)} P_a + [Q_j(0) - Q_j{}^0] \tag{6}$$

In Eq.6, the value range of the desired price is $P_a \in [0, -C_j(0)]$.$Q_j(0)$ is the discharge quantity when the discharge warrant price is zero, and it is essentially equal to the enterprise's normal discharge quantity in the circumstance that it does not have trade. When the ask price is $P_a=0$, the purchase amount $Q_j(0)-Q_j^0$is the enterprise demand when the price of pollutant discharge warrant is zero. When the asked price is $P_a = -C_j(0)$, the buying price reaches the maximum marginal costs of pollution control. At this time, there is no need for polluters to trade and the buying amount is 0.

(2) The optimal quotation strategy of market makers. After the cost optimization strategy of polluters is defined, the goal of market makers is to optimize the quotation decision according to the reaction function of polluters. The reaction functions Eq. (5) and Eq. (6) of trading enterprises are brought into the model, and the original model is converted into the model in Eq. (7).

$$\begin{aligned} Max\pi_m = P_a \sum_{j=1}^{N2} [\frac{Q_j(0) - Q_j{}^0}{C_j{}'(0)} P_a \\ + \left[Q_j(0) - Q_j{}^0\right] \\ - P_b \sum_{i=1}^{N1} [-\frac{Q_i{}^0}{C_i{}'(0)} P_b] - I_m(TQ) \end{aligned}$$

$$\begin{aligned} s.t. \sum_{j=1}^{N2} [\frac{Q_j(0) - Q_j{}^0}{C_j{}'(0)} P_a + \left[Q_j(0) - Q_j{}^0\right] \\ = \sum_{i=1}^{N1} \left[-\frac{Q_i{}^0}{C_i{}'(0)} P_b\right] \end{aligned}$$

$$P_a \geq 0, P_b \geq 0, Q_j \geq 0, Q_i \geq 0 \tag{7}$$

Proposition 3.1: In the emission trading market, the optimal bid price P_b and the optimal asked price P_a that are formulated by the market maker can be expressed as Eq. (8):

$$P_b = \frac{-[\frac{I'm}{C_i{}'(0)} + 1/2] \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0]}{\frac{\sum_{i=1}^{N1} Q_i(0)}{C_i{}'(0)} + \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0]}$$

$$P_{a=} = \frac{[I'm - \frac{C_i{}'(0)}{2} / C_i{}'(0)] \sum_{i=1}^{N1} Q_i(0) - \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0]}{\frac{\sum_{i=1}^{N1} Q_i(0)}{C_i{}'(0)} + \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0]} \tag{8}$$

and the optimal price difference can be expressed as Eq. (9):

$$\Delta P = [I'm - \frac{C_i'(0)}{2}]$$

Proof: Solve model (7) by constructing the Lagrange function (Eq. 10).

$$L = \pi m + \tau\{\sum_{i=1}^{N1} - \frac{Q_i(0)}{C_i'(0)} P_b - \sum_{j=1}^{N2} [\frac{Q_j(0) - Q_j{}^0}{C_j'(0)} P_a + Q_j(0) - Q_j{}^0]\} \tag{10}$$

The first order conditions of optimization are the following (Eq. 11):

$$\frac{\partial L}{\partial P_a} = 2P_a \sum_{j=1}^{N2} \frac{Q_j(0) - Q_j{}^0}{C_j'(0)} + \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0] - \tau \sum_{j=1}^{N2} \frac{Q_j(0) - Q_j{}^0}{C_j'(0)} - I'm \sum_{j=1}^{N2} \frac{Q_j(0) - Q_j{}^0}{C_j'(0)}$$

$$\frac{\partial L}{\partial P_b} = 2P_b \sum_{i=1}^{N1} \frac{Q_i(0)}{C_i'(0)} - \tau \sum_{i=1}^{N1} \frac{Q_i(0)}{C_i'(0)} + I'm \sum_{i=1}^{N1} \frac{Q_i(0)}{C_i'(0)}$$

$$\frac{\partial L}{\partial \tau} = \sum_{i=1}^{N1} - \frac{Q_i(0)}{C_i'(0)} P_b - \sum_{j=1}^{N2} [\frac{Q_j(0) - Q_j{}^0}{C_j'(0)} P_a + Q_j(0) - Q_j{}^0] \tag{11}$$

The first order conditions of optimization are the following (Eq. 12):

$$P_b = \frac{-[\frac{I'm}{C_i'(0)} + 1/2] \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0]}{\frac{\sum_{i=1}^{N1} Q_i(0)}{C_i'(0)} + \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0] / C_j'(0)}$$

$$P_a = \frac{[I'm - \frac{C_i'(0)}{2} / C_i'(0)] \sum_{i=1}^{N1} Q_i(0) - \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0]}{\frac{\sum_{i=1}^{N1} Q_i(0)}{C_i'(0)} + \sum_{j=1}^{N2} [Q_j(0) - Q_j{}^0] / C_j'(0)}$$

$$\Delta P = P_a - P_b = I'm - \frac{C_j'(0)}{2} \tag{12}$$

According to proposition 3.1, the best quotation that is made by market makers is a function of marginal information costs, marginal pollution control costs and initial allocation of pollutant discharge warrant. Compared with the pricing methods, such as government pricing and bidding, the significant difference in market makers' prices is due to the following two aspects.

(1) The quotation of the market maker is based on the optimal strategy of polluters. The optimal price not only needs to consider the pollution treatment costs but also needs to consider the distribution of the warrants, which will play an optimization role in the price of the pollutant discharge warrants.

(2) The equilibrium price that is determined by the three-player game is built based on the best interests of the three parties and conforms to the incentive compatibility constraint condition, which makes the quotation of market makers feasible in emissions trading. However, compared with the equilibrium price in the bidding market, there is no significant quantitative relationship between the optimal price that is set by market makers and the equilibrium price.

The price difference seems to be part of the benefit that polluters transfer to market makers, but the conclusion of proposition 4.1 shows that the optimal price difference is composed of the marginal information costs of market makers and the marginal treatment costs of the demand enterprises when the pollution volume is 0. The pollution control level of demand enterprises is one of the main factors that determine the price difference. However, due to the stickiness of the assets in the short term, the marginal treatment costs when the amount of pollution that is discharged by the enterprise is 0 is a constant value, and its size depends on the treatment capacity of the pollution treatment equipment of the enterprise. Therefore, the price difference in the short term mainly depends on the marginal information costs of market makers, and the price difference is essentially the manifestation of the information transaction costs. Obviously, the system measures that can reduce the marginal information costs of market makers are beneficial to reducing the price difference. Market makers with better information, more professional information management and lower information transaction costs will find it easier to carry out market transactions. This observation is consistent with the conclusion of Kedia and Zhou (2011) empirical study. These authors pointed out that the information advantages of local market makers are a very valuable factor in reducing transaction costs.

Proposition 3.2: In the market quotation market of market makers, there are two necessary conditions for the transaction: $I'm < -\frac{C_i'(0)}{2}$ (1), which represents that the marginal information costs of market makers are less than $-\frac{C_i'(0)}{2}$, and (2)$Q_j(0)$-$Q_j0>0$, which represents that the normal amount of pollutant discharge of the enterprise with no trading demand for pollutant discharge certificates is greater than the initially allocated amount of pollutant discharge.

Proof: Proof by contradiction. When the transaction occurs, obviously there are $P_b>0$ and $P_a>0$. If $I'm \geq -\frac{C_i'(0)}{2}$ or $Q_j(0) - Q_j{}^0 \leq 0$, according to statement 1, we will get $P_b \leqslant 0$, which contradicts condition $P_b>0$. Therefore, $I'm < -\frac{C_i'(0)}{2}$ or $Q_j(0) - Q_j^0 > 0$.

The necessary conditions for the transaction in proposition 3.2 indicate that if the market information costs are too high or the initial distribution of pollutant discharge warrants is extremely uneven, it will be difficult for market transactions to occur. Since the initial allocation of emissions permits is an exogenous variable, the trading efficiency problem that is caused by this situation cannot be effectively solved through the pricing mechanism of the trading market. If the enterprises with high pollution control costs are allocated too many licenses while the enterprises with low pollution control costs are allocated too few, or if the initial distribution is unbalanced due to the influence of market forces, the market transaction efficiency will be reduced.

Therefore, a free distribution scheme based on historical emissions may lead to inefficient trading. According to proposition 4.2, it can be improved by adding indicators to assess the pollution control abilities of enterprises. In addition, it is also necessary to control the total amount of pollution discharge and to recycle or cancel, in a timely manner, the residual emission discharge certificates that are generated by a project closing, transferring or stopping. In addition, the initial allocation system is adopted to ensure that the emission discharge certificates can be reasonably distributed among enterprises.

4. Simulation and results

4.1 Simulation setting

According to Li et al. (2019), the simulation platform is Fable (Functional Agent-Based Language for Simulation). The initial variables in this simulation mainly include the following: the initial ask price of pollutant discharge certificates, the initial bid price for emissions permits, the emission reduction costs (the mean and variance of higher emissions reduction costs and lower emissions reduction costs), the number of enterprises (the number of enterprises with higher emissions reduction costs and the number of enterprises with lower emissions reduction costs), the profits per unit of product, the probability of illegal supervision, the amount of the penalty for violations, the average product market demand, the variance of the product market demand, the number of pollutant discharge certificates and the variance of the pollutant discharge certificates that are available for allocation. Input data is generated randomly based on the model setting and results.

4.2. Simulation result

To meet the research requirements, four research variables are set: the price difference, the trading volume, the market maker's profits and the polluter's profits. Considering that the time cycle is an important factor in the reliability of response simulation results, this study observed the stability of 50 cycles of simulation operations and analyzed the reliability of the indicators. The simulation results are shown in Fig. 1.According to the simulation results of the quotations that are made by market makers in Fig. 1, the trends of the quotations that are made by market makers and the variation of the price difference are relatively stable over the 50 operating cycles, and the fluctuation of the quotations is relatively small. After running for approximately 50 cycles, the quotation increased from a 2000 yuan/ton bid and a 2124 yuan/ton bid to about a 3250 yuan/ton bid and a 3500 yuan/ton bid, respectively, and then stabilized. In practice, Hebei Province increased the base price of sulfur dioxide to 3,000 yuan/ton in 2012, which was similar to the numerical results of this simulation, indicating that the simulation results were in line with the actual situation.

The simulation can promote the realization of the market price discovery mechanism through the market maker's quotation. According to the simulation results of the market trading volume in Fig. 2, the average market buying volume and selling volume fluctuate around the axis of 6500, and the graph's consistency is good. This result shows that the buyer and seller trends are in line, and the market is very active. Based on the average purchase volume and selling volume of 6,500, the total trading volume of each issue can reach 260,000 units. Based on the total quota of 600,000 points, the trading proportion is as high as 43%, which will optimize the rational allocation of emissions permits. However, as shown in the figure, the volatility of the average selling amount is relatively small, and the volatility of the buying amount is relatively large, which indicates that the large volatility of the buying amount will aggravate the uncertainty of the market demand for pollutant discharge warrants. Market makers who act as market organizers need to have a certain amount of reserves to deal with market risks.

According to the simulation result of the market maker's profits in Fig. 3, during the 50 operating cycles, the profits of the market maker mainly fluctuates between -5 million and -17.5 million, and the profits greatly fluctuate. There are two main reasons for this phenomenon. (1) The emissions quotas that are set by this research cannot be stored. That is, the current period's quota cannot be used for the next phase of trading, which will result in storage costs for market makers and cause losses that cannot be traded at maturity. (2) Corporate buying volumes are highly volatile, which increases the risk of market makers' trading.

According to the simulation result of the market maker's revenue in Fig. 4, in the 50 cycles of operation, the returns of the emission trading system are all positive, indicating that the market is more efficient. In the environment of the number of enterprises, corporate income fluctuates on the axis of about 2.75 million, in other cases it fluctuates on the axis of about 2.5 million, but at this time the degree of fluctuation of system revenue is small. This shows that in market maker trading, system returns are more stable in markets with unbalanced types of quantities.

Based on the above analysis results, (1) the increase in the number of different types of enterprises will affect the market maker's quotation level, but it will not change the price trend. (2) At the same time, the imbalance of the number of different types of enterprises will slightly reduce the system revenue, but it will increase the system revenue stability. Therefore, in the environment of information asymmetry, emissions trading is the key to solving environmental externalities using market means; however, the basic condition for the effective implementation of this measure is to establish a perfect emissions trading market mechanism.

In the practice of emissions trading in China, the trading market presents the phenomenon of small trading volumes and large fluctuations in the trading price, and emissions trading is still in the growth stage. On the surface, the lack of vitality seems to be the result of low willingness to trade and a shortage of sellers; however, at its essence, the root of this phenomenon lies in the imperfect market structure and the lack of a price discovery mechanism in the market. The key factor lies in the fact that the market positioning of the emissions trading center is not clear and the operating form is passive. Moreover, there is no function that promotes the law of value and eliminates the influence of information asymmetry.

The results of the analyses show that an efficient emissions trading market needs to meet two basic conditions:

1) due to the information asymmetry of the emissions treatment costs of each enterprise, an effective price discovery mechanism is needed to promote the effectiveness of the law of value and make the trading price within the tradable range;

2) in an information asymmetric environment, polluters are highly motivated to sell their emission permits, which is the key to improving the market transaction efficiency.

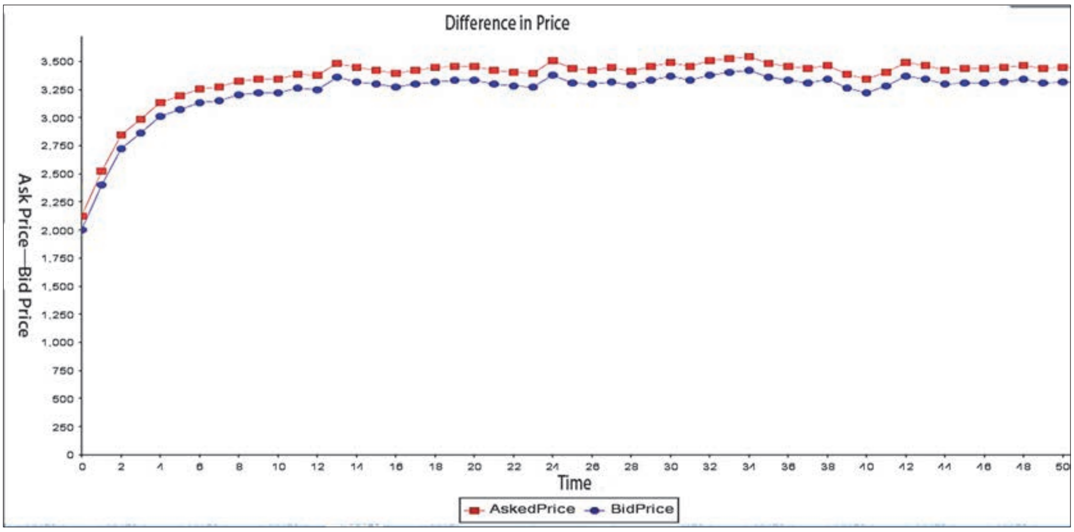

Fig. 1. Simulation diagram of the market maker quotation

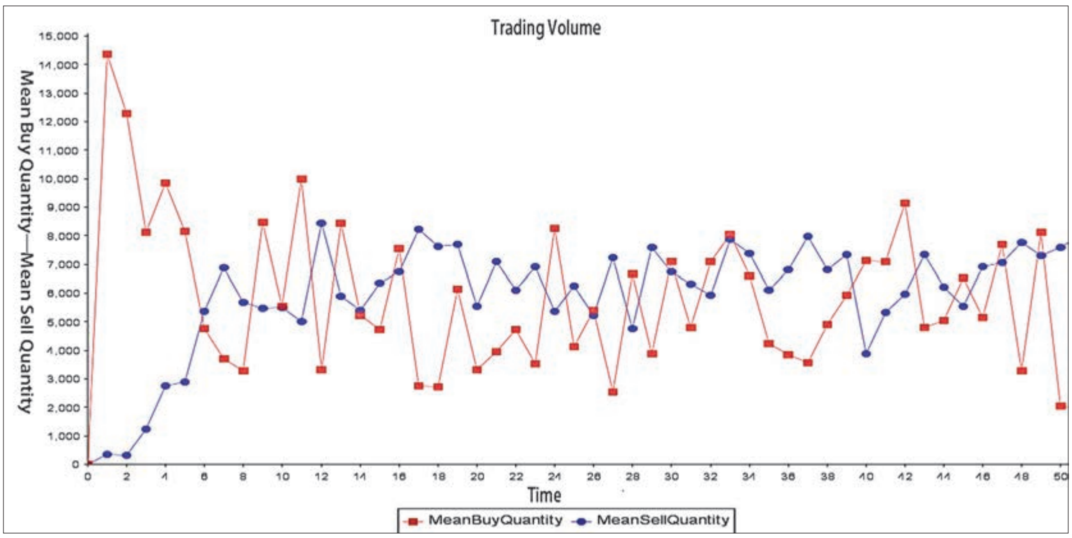

Fig. 2. Simulation diagram of the trading volume

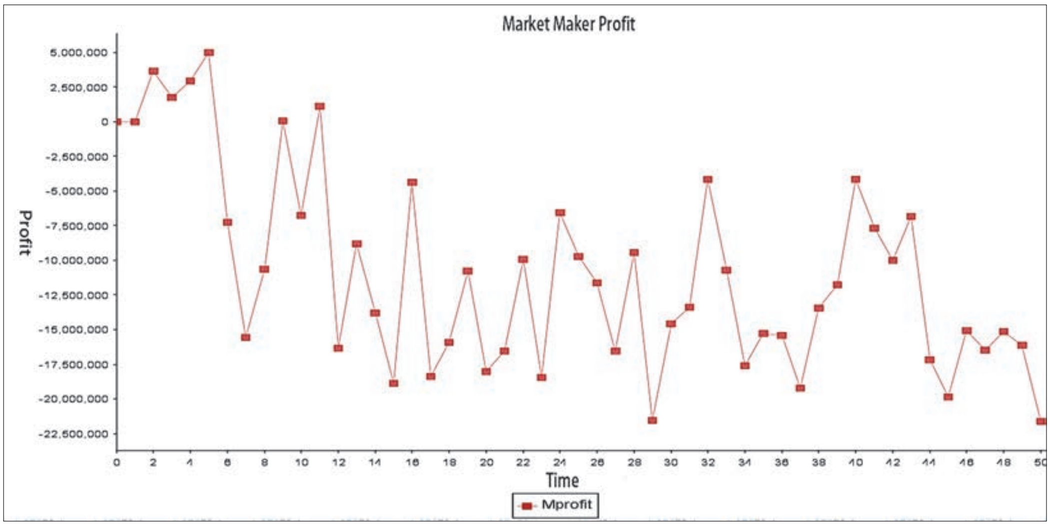

Fig. 3. Simulation diagram of the market maker's profits

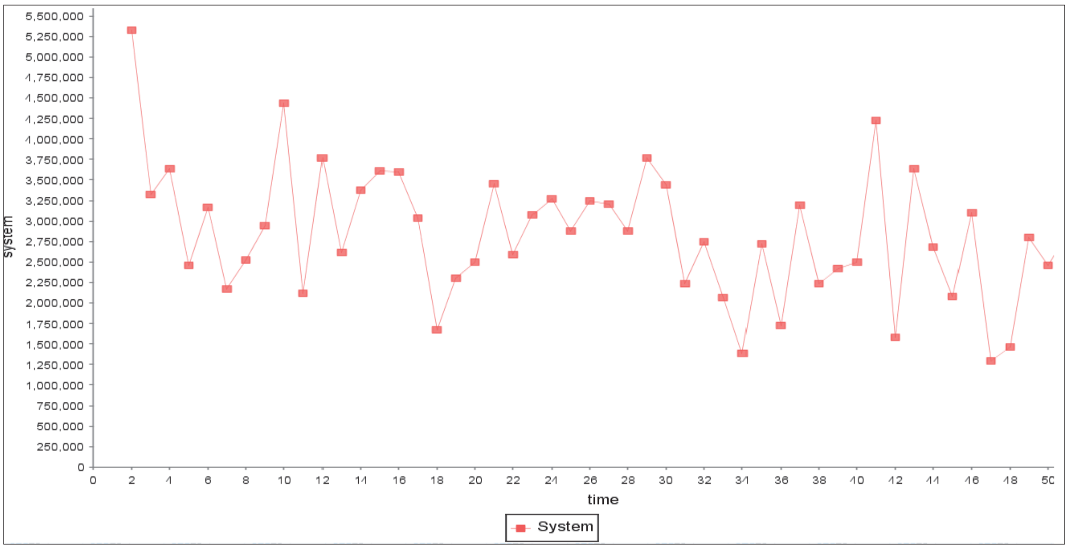

Fig. 4. Simulation diagram of the market maker's profits

5. Conclusions

In order to evaluate the effectiveness of the market maker's quote trading system in emissions trading, a system strategy for the market maker's quote trading was developed. In the short-term environment, this paper constructs a tripartite dynamic game model of market maker's quotation to study the formation mechanism of market maker's optimal quotation. The institutional cost model of the market maker's quotation transaction is compared with the system cost of the market maker's system.

Under the long-term environment, the evolution efficiency of the sewage trading market is analyzed through simulation. The main innovation conclusions include:

(1) The optimal quotation of the market maker is affected by the marginal information cost, marginal pollution control cost, and the initial allocation amount of the emission warrants.

(2) Excessive market information costs, extremely uneven initial allocation of emission warrants, and free allocation schemes based on historical emissions standards may lead to inefficient transactions.

(3) Under the premise of the same transaction volume, compared with the auction trading mechanism, market maker quotes can save social information costs in large-scale markets.

(4) For the purpose of saving the cost of social information, the implementation of the market maker's quotation trading system should first improve the trading willingness of polluting enterprises, which includes effective market supervision mechanisms and trading incentive mechanisms.

(5) The market maker's quotation trading not only has a good price discovery function, but also can improve market liquidity in a variety of environments such as sharp price fluctuations and market power.

(6) The spread consists of two parts: the marginal information cost of the market maker and the marginal governance cost of the company that requires the emission warrants. The increase of the price difference will reduce the system's income. In the

emission trading market, the market maker's price range should be limited.

According to the comparative analyses, this paper proposes the view that the introduction of market-making price trading can improve the current pollution market mechanism. On the one hand, market makers are professional market organizers with high enthusiasm for trading; on the other hand, market makers can reduce the uncertainty of business transactions and the asymmetry of market information through market making and promote the role of the law of value.

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