Emission Permits Trade of Carbon Based on the Game Theory of Double Auction

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Abstract As the world's largest carbon resources country with relatively great carbon emission, China has just started its carbon trade. China is only a passive participant in international carbon trading market, rarely participating in the project of Clean Development Mechanism (CDM). Therefore, trade market of emission permits can be divided into primary and secondary trading markets. During the definition of emission permit, we found out that the ways of emission trade at secondary carbon trade market is the key to the research on carbon trade, which can realize the allocation efficiency and utilization efficiency of resources. Then, feasibility of implementing auction system of emission permits trade in China is analyzed from the aspects of legal protection, technical support, and supervision and management. Chatterton and Samuelson double action model is adopted to determine the market hammer price for market clearing. In this auction, a seller and a buyer offer the asking price and bid price for a unit of emission permits, respectively. And the bidding strategy is determined in order to obtain the maximum profit for both seller and buyer. Game Model for carbon emission permits is established. Finally, allocation efficiency of emission permits trade market of carbon is studied and the Nash Equilibrium in this model is analyzed, so as to provide theoretical references for emission permits trade of carbon in China.

Key words Carbon emission permits; Game theory; Nash Equilibrium; Allocation efficiency; China

China, having the largest population in the world, is still at an early stage of economic development. And economic development is often accompanied by some environmental problems. In order to shake off poverty as soon as possible, China is more inclined to conduct predatory development on its limited environment resources. Thus, environmental pollution becomes far more serious than most developed countries. Faced with increasingly serious environmental problems, people begin to rethink the price for unreasonable development and try to find out the method for controlling and restoring the conditions for human survival.

As government pays more attention to pollution control, environmental protection departments in China have begun to use carbon emissions trade to control the environmental pollution in China according to the carbon emissions trade in the world. Moreover, for a developing country like China, insufficient investment fund for environment becomes a bottleneck for environmental transformation. And cost minimization can be realized by market mechanism of carbon emissions trade, so as to achieve the redistribution of environmental capacity during social development under financial constraints, and to provide more adequate theoretical support for carbon emissions trading polices. Research on carbon emissions trade can determine its role in sustainable development in China, is conducive to develop new policy tools for environmental management, and helps to realize the objectives of environmental management [1].

1 Feasibility analysis on establishing the emission permits trade of carbon

Emission permits trade market can be classified into primary and secondary trading markets. In the primary market, environmental management departments have allocated emission permits to polluting enterprises for free or by auction. And in the secondary market, after the definition of initial emission permits, secondary transaction of emission permits among enterprises can achieve the circulation of emission permits among enterprises, which is a readjustment of the primary allocation of emission permits. After the definition of emission permits, trade of carbon emissions at secondary market can realize both allocative efficiency and use efficiency of resources. Therefore, the key for carbon trade research is to pay attention to the means of emission trade in secondary carbon trade market.

Feasibilities of implementing the emission permits trade auction system in China are summarized. Firstly, protecting market economy by legal belongs to the legal economy. Handling affairs in accordance with the law is a basic requirement of legal economy. And implementation of emission permits trade system also needs the protection of the law. In order to comprehensively carry out the emission permits trade as soon as possible, we should strengthen the control of total quantity, promote the legislative process of emission permits trade, standardize the total quantity control and emission permits trades by law, and clearly regulate the contents in the *Environmental Protection Law* and related pollution control laws. Secondly, implementing emission permits trade system also needs corresponding technical supports, such as calculation of environmental capacity, allocation of emission targets, monitoring of sewage emission, and management of license. Under the current technical conditions, China has already grasped all the techniques for emission permits trade; and many places already have the conditions for the implementation of emission permits trade. Thirdly, effective sewage management and supervision on pollutant discharging unit is a necessary condition for the implementation of emission permits trade system. Effec-

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tive emission supervision can ensure that the pollutant discharging unit will follow the pollution discharge license, so that pollutant discharging units without qualified pollution discharge license may take the initiative to buy the license (or pollution index). At the same time, effective monitoring can also ensure the reliability of pollution discharge license provided by licensor[2].

2 Establishment of model

In the carbon trade market, supply side offers emission products and demand side buys emission products. Transaction price is finally determined through bargaining. Pricing of carbon emission permits is studied by using the double auction method. During the auction, both buyer and seller offer their prices at the same time. Then, they provide asking price and bid price, respectively. Finally, the market price is determined for market clearing.

Chatterjee and Samuelson Double Auction Model is used[3]. Assuming that a seller and a buyer offer their asking price p_s and bid price p_b for a unit of emission permit, cost of the product is c for the seller and the value of this product is v for the buyer. And values of c, v, p_s and p_b are taken within the range of $[0,1]$. If $p_s \leqslant p_b$, the hammer price is $p = (p_s + p_b)/2$, with the utilities of seller and buyer being $u_s = (p_s + p_b)/2 - c$ and $u_b = v - (p_s + p_b)/2$, respectively. If $b_s > p_b$, there is no trade and the utility is 0.

Since the seller knows c and the buyer knows the v, c and v belong to private information. Thus, c is the type of seller and v is the type of buyer. The process of auction is a Bayesian game[4].

Strategy of seller (asking price) p_s is a function of c, which is $p_s(c)$; strategy of buyer (bid price) p_b is a function of v, which is $p_b(v)$. Pricing strategy is determined by the maximizing profit both buyer and seller; and the optimal strategy is equal to the solution of the following optimization problem.

3.1 Profit maximization of seller

$$\max_{p_s}\{[\frac{1}{2}(p_s + E(p_b(v) \mid p_b(v) \geqslant p_s)) - c] \cdot \text{Prob}(p_b(v) \geqslant p_s)\},$$

where $E(p_b(v) \mid p_b(v) \geqslant p_s))$ is the expected bid price of seller if the asking price of a given seller is lower than the bid price of buyer. $\text{Prob}(p_b(v) \geqslant p_s)$ stands for the probability of $p_b(v) \geqslant p_s$, that is probability of asking price lower than bid price.

3.2 Profit maximization of buyer

$$\max_{p_b}\{[v - \frac{1}{2}(p_b + E(p_s(c) \mid p_b \geqslant p_s(c)))] \cdot \text{Prob}(p_b \geqslant p_s(c))\},$$

where $E(p_s(c) \mid p_b \geqslant p_s(c))$ is the expected asking price of buyer if the asking price of a given seller is lower than the bid price of buyer.

Strategic combination of $p_s^*(c)$ and $p_b^*(v)$, which is $(p_s^*(c), p_b^*(v))$, is a Bayesian equilibrium. Since there are many Bayesian equilibriums in this game, we should consider the following linear strategy equilibrium first:

$$\begin{cases} p_s(c) = \alpha_s + \beta_s c \\ p_b(v) = \alpha_b + \beta_b v \end{cases}.$$

Assuming c and v are evenly distributed in $[0,1]$, we obtain that $p_s(c)$ and $p_b(v)$ have shown even distribution in $[\alpha_s, \alpha_s + \beta_s]$ and $[\alpha_b, \alpha_b + \beta_b]$, respectively. Hence, we have

$$\begin{aligned} \text{Prob}\{p_b(v) \geqslant p_s\} &= \text{Prob}(\alpha_b + \beta_b v \geqslant p_s) \\ &= \text{Prob}(v \geqslant (p_s - \alpha_b)/\beta_b) \\ &= 1 - \text{Prob}\{v \leqslant (p_s - \alpha_b)/\beta_b\} \\ &= (\alpha_b + \beta_b - p_s)/\beta_b. \end{aligned}$$

Introduce the $E(p_b(v) \mid p_b(v) \geqslant p_s) = \dfrac{\frac{1}{\beta_b}\int_{p_s}^{\alpha_b+\beta_b} x\mathrm{d}x}{\text{prob}\{p_b(v) \geqslant p_s\}} = \frac{1}{2}(p_s + \alpha_b + \beta_b)$ into objective function of seller. Hence, we have $\max_{p_s}\{\frac{1}{2}[p_s + \frac{1}{2}(p_s + \alpha_b + \beta_b)] - c\}\frac{\alpha_b + \beta_b - p_s}{\beta_b}$.

The first order optimality condition means $p_s = \frac{1}{3}(\alpha_b + \beta_b) + \frac{2}{3}c$.

In the same way,

$$\begin{aligned} \text{Prob}\{p_b(v) \geqslant p_s\} &= \text{Prob}\{p_b \geqslant \alpha_s + \beta_s c\} \\ &= \text{Prob}\{c \leqslant (p_b - \alpha_s)/\beta_s\} \\ &= (p_b - \alpha_s)/\beta_s. \end{aligned}$$

Introduce the $E(p_s(c) \mid p_b \geqslant p_s(c)) = \dfrac{\frac{1}{2}}{\text{prob}(p_b \geqslant p_s(c))}\dfrac{1}{\beta_s}\int_{\alpha_s}^{p_b} x\mathrm{d}x = \frac{1}{2}(\alpha_s + p_b)$ into the utility function of buyer. Hence, we have $\max_{p_b}(v - \frac{1}{2}[p_b + \frac{1}{2}(\alpha_s + p_b)]) \cdot \frac{p_b - \alpha_s}{\beta_s}$. The first order condition means $p_b = \frac{1}{3}\alpha_s + \frac{2}{3}v$.

According to the two first order conditions, the equilibrium linear strategy is

$$\begin{cases} p_s(c) = \frac{1}{4} + \frac{2}{3}c \\ p_b(v) = \frac{1}{12} + \frac{2}{3}v. \end{cases}$$

3 Result analysis

Under linear equalization, when $c > \frac{3}{4}$, asking price of seller is $p_s(c) = \frac{1}{4} + \frac{2}{3}c$, which is lower than the cost but higher than the highest bid price of seller $p_b(1) = \frac{3}{4}$. Thus, the trade does not occur. When $v < \frac{1}{4}$, bid price of buyer is higher than its value but lower than the minimum asking price of seller $p_s(0) = \frac{1}{4}$. Thus, the trade also does not occur. Only when $p_b(v) \geqslant p_s(c)$, that is $v \geqslant c + \frac{1}{4}$, can the buyer and seller close a deal.

According to Bayesian Game Model, the buyer and seller can make a deal at $p = (p_s + p_b)/2$. Under linear equalization, trade price is $p = \frac{1}{6} + \frac{1}{3}(c + v)$. And the profits of both sides are $u_s = \frac{1}{6} + \frac{1}{3}v - \frac{2}{3}c$ and $u_b = \frac{2}{3}v - \frac{1}{3}c - \frac{1}{6}$, respectively. And net income of the whole society is $u = u_s + u_b =$

$v-c$.

By adopting auction model, trade price after bargaining is an equilibrium price. Bid price of buyer is real, which is the authentic assessment on commodity with emission permits. Thus, the optimal allocation of resources is achieved. Government or market organizer only needs to design a compatible-incentive auction mechanism. That trading participants tell the truth is a dominant strategy[5]. No matter how the other participants act, telling the truth is the most favorable. Therefore, equilibrium under this mechanism is the optimal solution of system.

Under market environment, information gathering is very difficult for market participants. For instance, government can accurately estimate neither the cost function of seller nor the income function of buyer. And efficient allocation of resources can be achieved by offering the real price and by determining the reasonable price in market transaction.

Auction of carbon emission permits is a reasonable and effective way of selling. Bid price depends on the value of carbon emission permits. Enterprises with high economic benefits and high marginal pollution control cost can buy the carbon emission permits at a relatively high price; while enterprises with low economic benefits but high marginal pollution control cost may gradually be eliminated. Then, through trade of emission permits, environmental protection funds will flow to enterprises with low marginal pollution control cost; and emission permits will flow into the enterprises with high economic benefits. Therefore, optimal allocation of environmental capacity and environmental protection funds within a region is achieved[6].

4 Conclusion and discussion

Auction of carbon emission permits has broad market prospects, as well as huge profit margins, which can reduce the carbon dioxide, save energy and reduce emissions, realize economic sustainable development, and deal with global warming. However, reasonable adjustment based on the local situation is necessary during practice, so that auction of carbon emission permits can play its due role.

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碳排放权交易的双向拍卖博弈研究

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摘要 碳交易是为促进全球温室气体减排,减少全球二氧化碳排放所采用的市场机制,是将气候变化这一科学问题、减少碳排放这一技术问题与可持续发展这个经济问题紧密地结合起来,以市场机制来解决科学、技术、经济综合问题。而作为世界上最大的碳资源国家和碳排放较大的国家,碳交易在中国刚刚起步,中国仅是国际碳交易市场的被动参与者,只少量地加入了清洁发展机制(CDM)项目。为此,首先将排污权交易市场可分为一级和二级交易市场,通过排污排污权界定发现,二级碳交易市场的排放权交易方式与方法是碳交易研究的重点与核心,可以实现资源的配置效率和使用效率,并从面法律保障、技术支持和监督管理3个方面分析了国实施排污许可证交易拍卖制度的可行性。其次,采用查特金和萨缪尔逊双方叫价拍卖模型,在双方叫价拍卖中,假设模型中一个卖者和一个买者对一单位的排放权进行报价,卖者提出要价,买者提出出价,最后确定市场成交价清算市场。从买者和卖者获利最大角度确定报价策略,建立了碳排放权交易的博弈模型。最后,研究碳排放权交易市场的配置效率问题,并对模型中的纳什均衡进行了分析,试图为中国的碳排放权贸易提供理论的参考依据。

关键词 碳排放权;博弈;纳什均衡;配置效率