Does initial allocation of carbon quota do well on regional economy and CO$_2$ emission?

Yalin Chen$^1$, Jiaojiao Liu$^1$, Haoxin Xu$^2$

$^1$School of Management and Engineering, Nanjing University of Finance & Economics
$^2$Accounting Finance and Management, University of Bristol

Abstract. This study attempts to investigate the impact of the initial allocation quotas and carbon trading prices on regional economy development and CO$_2$ emissions. The models under different initial allocation were established respectively. Shanghai was taken as the instance to investigate the varying of GDP and CO$_2$ emission under different scenarios. The results showed that the increased carbon trading would reduce the amount of carbon emissions and GDP while the proportion of free quotas had gradually declined. and the varying carbon trading prices resulted in amplifying fluctuating in the CO$_2$ emissions and the total GDP. The research in this paper would help to optimize the initial carbon quota plan.

1. Introduction

Global warming has been seriously affecting the sustainable development of human society. Then the State Council announced that Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei, and Shenzhen had launched seven trials of carbon trading in 2011, and the generalizing domestic carbon emissions trading market has been established in 2017. The initial quota allocation is one of the most challenging and significant parts of designing trade market. The smooth implementation of carbon-trading depends largely on a reasonable allocation of the initial quotas.

There are two kinds of scheme for industry to get the preliminary carbon quota: free scheme and the paid scheme. Wu, J., Fan, Y., & Xia, Y. (2016) revealed that free allocation lead to lower macroeconomic costs, while auction was better at adjusting the industrial structure. Liao, Z., Zhu, X., & Shi, J. (2015) simulated the initial allocation of carbon emission allowances. The result showed benchmark was more equitable in comparison to grandfathering.

Since carbon emission reduction is a long-term strategy for China, the economic performance of initial carbon quota allocation has been concerned besides the effectiveness of them. Zhou, P., Zhang, L., Zhou, D. Q., & Xia, W. J. (2013) modelled the economic performance of an interprovincial emission reduction quota trading scheme in China. The results showed that total emission abatement cost could decrease by over 40% through implementing.

Different initial carbon quotas will have varying effects on the enterprises utility, CO$_2$ emissions and GDP in the carbon-trading regions. This paper focused on the topic and organized as following: Firstly, a modified model is established according to the rules of the actual transaction market combining the unified pricing carbon emission allocation analysis model; Secondly, an adjusted regional model is presented according to the operation of Shanghai carbon trading market; Thirdly, based on the models, the GDP and CO$_2$ emissions under different scenarios considering the possible energy technology improvements are simulated and analysed.
2. Establishing and adjusting the Model

2.1. Primary free allocation model

The mainly free allocation forms, historic allocation, benchmarking method, and the hybrid method will be counted in the following discussion. Here, for the firm $i$, $x_i$ denotes the carbon emissions, $q_i$ is the output and $a_i$ is the basic quota the corporates obtained, $V_i$ is the company’s output value under historic allocation, $V_2$ is the company’s output value under benchmarking method. If the final quota obtained by the enterprizes is equal to the basic quota, $A_i=a_i$; in historic allocation scenario, enterprises obtain quotas based on the historical carbon emissions, $A_i^G=x_i$; in benchmarking allocation scenario, the quota for the enterprise is the result of the company’s output value and the industry benchmark value. $b$ denotes the industry benchmark and the carbon emission per unit product of the nth firm serves as the baseline value, then $b=x_nq_n^{-1}, A_i^B=bq_i$; in the mixture scenario, firms get quotas for weighting historical law and baseline method $A_i^G=V_i*x_i+V_2*bq_i$. The total carbon emission quota of the industry denotes as $C$. If $\sum a_i > C$, multiply the adjustment factor $T=C(\sum a_i)^{-1}$ based on the quota of each enterprise. The final quota for the company is $A_i$. The basic quota is multiplied by a total factor.

When adopting the historical method, the basic quota obtained by firm $i$ is $A_i^G=x_i$, and the total factor is $T=C(\sum x_i)^{-1}$, so the final quota obtained by the company as follows.

$$A_i^G=x_i, T=C(\sum x_i)^{-1}$$  (1)

When adopting the benchmarking allocation, the basic quota obtained by firm $i$ is $A_i^B=bq_i$, and the total factor is $T=C(\sum bq_i)^{-1}$, so the final quota obtained by the company as follows.

$$A_i^B=bq_i, T=C(\sum bq_i)^{-1}$$  (2)

When adopting the mixture method, the basic quota obtained by firm $i$ is $A_i^C=V_i*x_i+V_2*bq_i$, and the total factor is $T=C(V_1+x_1+V_2*\sum bq_i)^{-1}$, so the final quota obtained by the company as follows.

$$A_i^C=x_i+V_2*bq_i, T=C(V_1+x_1+V_2*\sum bq_i)^{-1}$$  (3)

Where, $y=V_1(V_2)^{-1}*(b^{-1})$ and $\bar{b} = \sum x_i(\sum q_i)^{-1}$, the average product carbon emissions in an field. When $V_1=V_2=1/2$

$$A_i^C=\left(\frac{1}{2}\right)*(A_i^G+A_i^B), when b=\bar{b}=\sum x_i(\sum q_i)^{-1}, then y=1$$

$$A_i^C(1+\frac{1}{y}) > A_i^B(1+y)^{-1}, when b<\bar{b}, then y>1. A_i^C \approx A_i^G, under historic allocation$$  (4)

$$A_i^G(1+\frac{1}{y})^{-1} < A_i^B(1+y)^{-1}, when b>\bar{b}, then y<1. A_i^C \approx A_i^B, under benchmarking method$$

When $V_1 \neq V_2$

$$\left\{ \begin{array}{l}
b < (V1(V_2)^{-1}) * \bar{b}, then y>1. A_i^C \approx A_i^G, under historic allocation \\
b > (V1(V_2)^{-1}) * \bar{b}, A_i^C \approx A_i^B, under benchmarking method 
\end{array} \right.$$  (5)

If there is no total industrial quota, according to historic allocation the firms will obtain quotas depending on the carbon emissions of the previous year, while the allocation will be based on the comparison of baseline between the firms and the industries. The carbon emissions of the products are higher than the baseline of the entire industry, the quota will increase; otherwise decrease. And the mixture of historic and baseline allocation depends on the weight of the two and performs weighting processing.

If there is total industrial quota, and the total amount of basic quotas obtained by the enterprise exceeds this quota, the historic allocation depends on the proportion of the company’s carbon emissions in the total carbon emissions of the industry; the baseline allocation depends on the enterprise’s output in the total output of the industry. Which is not related to its specific value. The mixture of historic and baseline allocation is built on industry baselines, carbon emissions per unit of
product weighting.

If the weights given to the historic allocation and the baseline allocation are equal, then the industry average product carbon intensity is greater than the industry benchmarking value, the former is closer to reality; otherwise, it is closer to the later. If the weight assigned to historic allocation and baseline allocation is not equal, then the assigned amount is determined by the industry baseline, industry average product carbon emissions, and weighting.

2.2. Improving model

Since the carbon emissions market is still in the primary stage, then free allocation forms are easier to be accepted. For each firm, to get initial carbon quota through historic allocation and the benchmark-ing method. No matter which methods of allocation and the government needs to give out the corresponding carbon emission rights according to the information that enterprises reporting data. Although the thorough investigations are carried out to make the allocation as fair as possible, it is still very difficult to collect more information about each firm. Next, we analyze the free allocation model that matches the reality. $H_0$ is the total allocation quota, $s_i(x)$ denotes the marginal governance carbon emission cost function, and $z_i(x)$ represents the cost function of the real marginal governance carbon emissions for each firm $i$. $T_i$ is the actual carbon emissions of the firm $i$, $h_i$ is the carbon emission right that the government gives out to the firm $i$ based on the information submitted by each firm. $x = T_i - h_i$ represents the total amount of carbon emissions that the enterprise $i$ should manage,

$C_i(x)$ represents the cost function of the firm $i$ that manages excess carbon emissions $x$. The allocation requirements for $H_0$ are as follows.

$$\sum_{i=1}^{n} h_i = H_0$$

$$0 \leq h_i \leq T_i$$

The purpose of the free allocation form is to identify an allocation plan under the same marginal governance carbon emission cost, which achieves a minimum social governance cost. Then the allocation decision model

$$\begin{align*}
\text{Min} \sum_{i=1}^{n} C_i (T_i - h_i) \\
\sum_{i=1}^{n} h_i = H_0 \\
0 \leq h_i \leq T_i, \quad i = 1, 2, \ldots, n
\end{align*}$$

The free allocation form described in (7) is the optimal method under the premise of completed information. However the problem is that (7) is the precise model when the information reported by enterprise is real, $s_i(x) = dC_i(x)/dx$. Actually, the marginal cost is not complete information necessarily, $s_i(x)$ is not equal to $dC_i(x)/dx$ absolutely. In order to obtain more carbon allocation quotas some companies may exaggerate their own marginal costs, which results in the government not being able to receive the real situation of the enterprise when the resources is configured, so we need to optimize the model in the next section.

2.2.1 Analysis on the carbon allocation of the unified price based on mixed auctions.

Based on the above model, assume that the government is an auctioneer and the enterprise is risk neutral and rational. Then the government auctions the carbon emission rights for a total of $H_0$, and $n$ companies participate in the bidding. We also assume the actual marginal governance costs function $z_i(x)$ of firm $i$ is non-public information and then the cost function $s_i(x)$ reported by firm $i$ to the government must be less than or equal to the cost function $z_i(x)$, so the government can only allocates carbon emission rights according to the cost function of firm $s_i(x)$, $s_i(T_i - h_i) = P$, where $P$ is a uniform price and the total amount of carbon emission is $H_0$.

The government selects the total amount of carbon emissions $H \leq H_0$, and the price $P \geq 0$. From the government, it hopes to maximize its utilities

$$\max \sum_{i=1}^{n} ph_i = pH$$
\[
\begin{aligned}
\sum_{i=1}^{n} h_i &= H_0 \\
n_i = T_i - h_i &= P, \quad i = 1, 2, \ldots, n \\
0 \leq h_i &\leq T_i, \quad i = 1, 2, \ldots, n \\
H &\leq H_0
\end{aligned}
\] (10)

The purpose of firm \(i\) is to maximize its revenue through the optimal quotation strategy \(h_i(p)\).

\[
\max \int_{T_{i-1}}^{T_i} (z_i(x) - p) \, dx = \max \int_{T_{i-1}}^{T_i} (z_i(x) - ph_i(p)) \, dx
\] (11)

The above formulas are the unified price auction model based on an uncertain supply. This improving model can reflect the game between enterprises and government. They both hope to achieve the maximization of their own returns more effectively where some information is not open to the public.

3. Simulation based on System Dynamics

The carbon trading mechanism is a typical complex system and influenced by multiple factors. System Dynamics can be used for the relationship between related variables within the system. For setting the parameters of SD modelling, we collected the data from National Statistical Yearbook, Energy Statistical Yearbook, China Carbon-trading Network, Shanghai Statistical Yearbook, National Bureau of Statistical of the People’s Republic of China, and emission factors from the IPCC 2006 CO\(_2\) emission factors. The simulation scenario can be adjusted through vary parameters as following section. Therefore, the Vensim simulation software is employed to simulate the entire carbon trading process.

3.1. Model construction

This model mainly covers the variables such as carbon dioxide emissions, total GDP, energy consumption, and investment in science and technology. Therefore, the causal circuit diagram made with Vensim is as follows.

![Figure 1. Karma circuit diagram](image)

The stock flow chart is shown in Figure 1. The CO\(_2\) emissions work as an important indicator of whether energy-saving and emission reduction can be completed.

![Figure 2. Stock flow chart](image)
For setting the parameters of SD modelling, we collected the data from National Statistical Yearbook, Energy Statistical Yearbook, China Carbon-trading Network, Shanghai Statistical Yearbook, National Bureau of Statistics of the People's Republic of China, and emission factors from the IPCC 2006 CO\textsubscript{2} emission factors. The simulation scenario can be adjusted through varying parameters as following section.

3.2. Simulation and analysis

3.2.1. Simulating scenario

When we explore the impact of initial allocation of carbon quota on the economy and environment in the Shanghai area, a simulation scenario is set up here:

\textit{Scenario I}: Considering the influence of the free proportion on the overall system when initial allocation occurs, the free proportion is reduced by 10\%, 30\%, and 50\%, respectively, under current conditions, then we observe the changes in total GDP and CO\textsubscript{2} emissions during the t-phase.

\textit{Scenario II}: According to the average price of the carbon-trading in the past five years was about ¥25, so the carbon-trading price was set at 30, 40, 50, and then the volatility changes in total GDP and CO\textsubscript{2} emissions during the t-phase are observed.

3.2.2. Results analysis

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{carbon_dioxide_emissions.png}
\caption{Carbon dioxide emissions under different free proportion}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{total_gdp.png}
\caption{Total GDP under different free proportion}
\end{figure}

The results indicate that the gradual reduction of proportion of free quota makes the total amount of CO\textsubscript{2} emission and GDP fall in Shanghai. Obviously, the high free proportion at the beginning actually reduces the companies’ emissions cost which has an enhanced effect on encouraging enterprises to reduce emissions. Then the promotion of the economy has played an inhibitory role.

3.2.3. Varying initial pricing
The results show that the increasing carbon-trading prices cause the CO$_2$ emissions and total GDP to continuously decline in Shanghai, and the decline will be an increasing trend which also predicts once the carbon-trading price rises, then the companies’ cost naturally increases and the profit declines. Although the emissions have become much less, it is at the cost of GDP.

4. Conclusions and implications
This work sorts out the policies of different carbon quota. Quotas are affected by carbon trading price, free quota proportion, and CO$_2$ emissions. From a macro perspective, different quota policies have a certain degree of impact on the regional economy (with regional GDP as a characteristic indicator). From a microscopic point of view, the auction is a necessary step after free allocation and the process is more fair and transparent. It is not only easier to provide incentives for emission reduction (characterized by CO$_2$ emission), but also to avoid excess quota problem.

China's carbon-trading market is still in preliminary construction, so this work uses the System Dynamics (SD) to analyze the impact of initial allocation of carbon quota and varies initial pricing on regional socio-economic and CO$_2$ emissions. In other words, maintaining the initial pricing at a reasonable lower level is the key to getting companies to try to enter the market. Only by slowly allowing prices to change according to the market can we reduce CO$_2$ emissions and stabilize GDP growth. However, the unified trading market has not yet been established due to the lack of national data and the effect of initial carbon quotas allocation on the social economy and the environment.

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