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论文题目： Design of optimal government carbon offsetting mechanism: a theory based on regional and industry perspectives

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论文题目：Design of Optimal Government Carbon Offsetting Mechanism: a Theory Based on Regional and Industry Perspectives

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摘要：This paper investigates the spatial and economic effects of carbon offset mechanism in closed economy and carbon tariff cooperation in open economies and proposes a policy design framework for internalizing carbon emission externality. A general equilibrium model and two-country extension model are theoretically derived for closed and open economies, respectively. In the general equilibrium model, numerical simulations are performed to obtain the optimal carbon reduction strategies for regions with diverse resource endowments, industrial structures and carbon market mechanisms. Implementing the carbon offset mechanisms is found to be effective in boosting market efficiency and social welfare. In the two-country extension model, trade-induced redistribution of the industries stimulates economies with carbon offsets to export green products, while those without focus on exporting generic products. This dynamics amplifies carbon emission externality, providing government an effective tool for regulating productions to maximize the total social welfare. Further analytical analysis shows that increasing the tax rate does not always decrease the international export volume due to the compensation effect of carbon offset mechanism. We also provide insights for policy formulation, highlighting the government's role in promoting carbon offset mechanisms and tax adjustments to incentivize green practices for societal welfare enhancement. Finally, this paper underscores the importance of international carbon cooperation and enhanced green trade in tackling the challenges of global climate change.

关键词： International tariff, Carbon offset mechanism, Resources endowments, Policy formulation, Social welfare

目录

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1. Introduction

Based on the consensus of the Paris Agreement and the goal of "striving to peak carbon dioxide emissions before 2030 and achieving carbon neutrality before 2060" (hereinafter referred to as the "double carbon" goal), China has actively introduced and implemented policies with carbon neutrality features and promoted reformation of the economy and society towards the low-carbon objective in an orderly manner. In November 2021, the State Council released the "2030 Carbon Peaking Action Plan", outlining key strategies to achieve carbon peaking by 2030. These strategies include transitioning to green and low-carbon energy sources, fostering advancements in green and low-carbon technology, enhancing carbon capture capabilities, and bolstering economic policies and market mechanisms. The State Council also emphasized that each region should promote green and low-carbon development based on local circumstances and should support the establishment of pilot cities aimed at achieving carbon neutrality. However, questions arise on how each region should scientifically formulate its own carbon peaking action plan and come out with the best paths to carbon emission reduction. These are the current key issues of urgent concern to both local and central governments in China. The investigation in this paper responds to this reality needs of carbon peaking path selection and aims to propose a methodology that can provide each region with a carbon peaking path that fits its resource endowment and industrial distributions and provide reference for its policy choices.

Consistent with international experience, China's carbon peaking path can be divided into three main categories: improving carbon pricing mechanism, developing negative carbon emission technologies, and developing clean energy technology. Carbon price and quantity mechanisms are the two useful tools for carbon pricing mechanisms. The former refers to influencing the carbon emission behavior of industrial parks by changing the price of carbon tax (Cui et al., 2014). The second approach involves setting up a carbon market (hereinafter referred to as "carbon market"), where industrial enterprises can lower their emission reduction costs through trading carbon emission rights (Cui et al., 2014; Jiang et al., 2016). China launched its first national Emissions Trading System (ETS) in July 2021, with the first batch covering eight high-carbon emitting industries. Negative emission technologies, which are mainly used to capture, treat and utilize atmospheric carbon dioxide. It can be broadly divided into two categories: one is to increase ecological carbon sinks, using biological processes to absorb carbon from the air and store it in forests, soil or wetlands; and the Carbon dioxide Capture, Use and Storage technologies (CCUS), both with the ultimate goal of reducing the carbon content in the atmosphere (Fan et al., 2023). Regarding clean energy technology, the advancement of clean energy technologies like wind, solar, geothermal, biomass, and nuclear power can help to fill the energy gap resulting from cutting carbon emissions, thereby promoting emission reduction during production processes (Liu et al., 2019).

Although all kinds of carbon emission reduction tools have a certain degree of environmental benefits, for the purpose of policy attention concentration and obtaining better results with limited effort, local governments should prioritize the management of emission reduction tools based on heterogeneous resource conditions when promoting regional carbon emission reduction. On the one hand, clean energy in China is rich but varied from region to region. The uneven spatial distribution of these resources across provinces has created significant disparities in the regional power grid structures (Li et al., 2019). By 2030, with full development, the northern and northwestern regions with long sunshine hours and abundant solar energy, are expected to see a 10% increase in solar power generation compared to 2015. The sea wind power in the eastern region and the inland wind power in the northwest region are strong, and the contribution of wind power generation to the local power structure is greater compared to other regions (Shen et al., 2019). As a general principle, provinces rich in clean energy should give priority in developing their clean energy potential. On the other hand, carbon emission intensity presents various levels among different regions due to their differences in industrial and economic structure. Regional heterogeneity of various carbon intensity will lead to differences in Marginal Abatement Cost (MAC). MAC in low-carbon regions keeps increasing, while MAC in high-carbon regions shows an inverted U-shaped trend of first increasing and then decreasing (Fu Jingyan and Dai Yuting, 2015). Finally, these different MAC features will lead to a large gap in the costs and benefits of participating in the carbon emission trading market among different regions. Further consideration is needed on the policy strength of each region to enhance enterprise enthusiasm for participating in the carbon market.

This paper presents the construction of a general equilibrium model taking into account the development level, technology path and resource endowment of each region. Firstly, carbon offset mechanisms in different regions are designed, and whether the social welfare would be improved after the entering to carbon emission trading market with various models for carbon offsetting is discussed. Furthermore, due to the negative externality of carbon emissions, competitive optimality is definitely inconsistent with social optimality. Therefore, international trade policies and industry-level tax and subsidy policies are introduced into the general equilibrium model to test whether social optimality can be achieved after policies are imposed. Finally, numerical simulations were performed under specific parameter settings, to analyze the selection of main carbon reduction path in different regions of different natural endowments and industrial structures.

The possible contribution of this paper is primarily seen in two areas. A general equilibrium model of closed economy is constructed theoretically, and optimal design of the carbon offset mechanism in different regions are analyzed and discussed. In the extended model, the open economy international trade model is built, which takes into account the international tariff between two economies, for the theoretical analysis of the policy lever. The research findings outlined in this paper hold significant values for decision-makers in policy. Firstly, it addresses the question of whether a carbon offset mechanism is necessary. If no carbon offset mechanism is introduced, the existing carbon cap-based carbon emission rights trading market can achieve the purpose of controlling carbon emissions, but the social welfare is not optimal, and the social welfare can be improved by introducing carbon offset mechanism. Furthermore, this paper addresses the issue of selectivity of the carbon offset mechanism. There are a variety of carbon offset mechanisms in the market, but different regions have different resource endowments and different industrial structures. This paper presents a methodology for choosing the most suitable carbon offset mechanism for different regions.

This paper is organized as the following: Chapter 2 presents a literature review related to the impact mechanism of the carbon market, the deficiencies of the single carbon market and the importance of non-carbon price instruments; Chapter 3 describes the general equilibrium model which is a general equilibrium model under closed economy; Chapter 4 presents the two-country extension model for open economic by superimposing international carbon tariff policy on the basis of the general equilibrium model to test whether the social optimal can be achieved after the policy is applied; finally Chapter 5 summarizes the main findings of this paper and provides suggestions to policy makers.

2. Literature review

Carbon market is regarded as an effective way to reduce global greenhouse gas emissions and deal with climate change thanks to its advantages of flexibility, cost saving and effectiveness (Jiang et al., 2016; Zhang et al., 2022). By analyzing the data from 100 cities in

China, it has been found that compared to non-pilot areas, the carbon market pilot regions had a lower rate of deadweight loss in the electricity market, and the improvement in market efficiency also leads to a greater reduction in carbon emissions (Li et al., 2022). Jin Wei and his colleagues tested the provincial datasets and found that the carbon market can stimulate emission reduction efforts by addressing the cost of carbon emission externalities, thereby enhancing emission efficiency and facilitating asset structure adjustments (Jin et al., 2022). However, China's carbon market, which began later than those in Western developed countries like Europe and the United States, mostly involves state-owned enterprises and faces challenges such as legislative delays and "focusing on compliance over trading" (Liu et al., 2015; Zhao et al., 2016). The carbon market does not negatively impact regional economic growth but has a limited effect on improving enterprise production efficiency. It can enhance the total factor productivity of emission-controlled firms but does not generate positive spillovers for non-controlled enterprises in the same industry within pilot regions (Hu et al., 2023). Wu and her colleagues discovered that the market mechanism, indicated by carbon price and market liquidity, did not significantly reduce carbon emission (Wu et al., 2021). Duan et al. quantitatively assessed the global economics and carbon emission impacts of China's carbon market in the context of globalization, revealing that it may bring certain welfare losses to China through the reduction of export competitiveness (Duan et al., 2023). In summary, while existing literature has extensively discussed the carbon market's effect on emission reduction, enterprise efficiency and industrial structure adjustment, the findings are inconsistent. Most studies evaluate the overall role of carbon market in pilot cities as experimental case studies, making it difficult to provide a basis to inform individual city decisions on carbon market participation. Further exploration of low-carbon transformation strategies in diverse regions is still needed.

Recently, as the practice intensifies and the attention shifts to regional heterogeneity, there is an increasing recognition of the limitations of carbon pricing mechanism and the potential of non-carbon pricing mechanism. The importance of the latter in emission reduction efficiency and equity has been preliminarily acknowledged. In the industrial production of developing countries like China, energy prices are typically higher than the costs of other production factors. The implementation of carbon pricing mechanism can, at least in the short term, increase the cost and utilization of fossil energy and impact the energy sector's growth, potentially curtail supply capacity and hinder economic expansion (Finon, 2019). Though theoretically, carbon pricing is the most efficient and least costly approach to emissions reduction (Zhang et al., 2022), in practice, economic complexities mean that a sole reliance on carbon pricing might not produce optimal solutions (Stern and Stiglitz, 2017). For instance, a regressive carbon tax can worsen income inequality (Stiglitz, 2019). An integrated approach, combining carbon pricing with non-pricing tools such as energy efficiency standards, industry regulation, and clean technology subsidies, can address both market and government failures (Finon, 2019; Stern and Stiglitz, 2017). Rosenbloom et al. also argued that an overemphasis on the efficiency of carbon pricing ignores its effectiveness, suggesting that a coordinated suite of policy tools is essential for achieving the goals outlined in Paris Agreement (Rosenbloom et al., 2020). Regarding the non-carbon pricing tools, they can function from three aspects: firstly, some empirical studies on the United States, China and India highlights the environmental benefits of these non-pricing carbon mechanisms (Shapiro and Walker, 2018; Wang et al., 2021; Duflo et al., 2018). Secondly, the emission reduction created by non-pricing carbon mechanisms can offset part of the carbon emissions, reducing the established emission targets and easing the pressure on carbon price level, alleviating the negative effect of rising carbon price on the allocation segment of social wealth, and improving total social welfare (Stiglitz, 2019). Thirdly, acknowledging the diversity of industries and their unique policy constraints, different industries have different technical paths and comparative advantages to achieve energy conservation and emission reduction (Duan et al., 2013). Targeting industrial regulation policies, rather than a one-size-fits-all carbon pricing policy, are more effective in promoting carbon emission reduction (Cullenward and Victor, 2020).

Despite extensive theoretical and empirical analyses of non-carbon pricing tools and their impacts on social welfare and emissions reduction, existing literature still lacks in providing a comprehensive theoretical discourse and numerical examination of the interplay between carbon pricing, carbon offset mechanisms, and the varied effectiveness of reduction strategies across different regions, all within the context of China's objective towards "carbon neutrality". This paper tries to fill this gap by constructing a low-carbon economic growth model to investigate the influence of carbon market and carbon offset tools on regional sustainable development. By using a dual approach combining theoretical analysis with quantitative simulations of the carbon emission reduction trajectories tailored to the distinct endowments of various regions, the study aims to identify the optimal low-carbon transition pathways.

3. General equilibrium model

The establishment of the analytical framework in this work starts with a closed economy which is segmented into three sectors: the production sector, the decarbonization sector, and the household sector. Let L represents the labor force in the economy and *K* represents the total capital.

3.1. The production sector

The production function in the production sector is assumed to be in the Cobb-Douglas form described as $Y = A(t)K^{\alpha}L^{\beta}\mu$. In the model, Y represents the output of product, A(t) is the time dependent overall technology level, μ represents the influence from random factors and is always smaller or equal to 1, α and β is the production weighting coefficient for capital and labor, respectively. We further assume that there is no impact from randomness (i.e., $\mu = 1.0$), and the production efficiency can only be improved through advancing the technology instead of through expanding the production scale (i.e., constant return A(t)=A to production scale, and coefficients satisfies $\alpha + \beta = 1.0$). Under these assumptions, the Cobb-Douglas model is tailored into the following form for the production sector when producing Product 1:

$$Y_1 = A_1 K_1^{\alpha} L_1^{1-\alpha} \tag{1}$$

The profit function is calculated by considering the total sale price of the products, the wage of labor force, the cost of capital, and the cost due to carbon emission:

$$\pi_1 = P_1 Y_1 - W L_1 - R K_1 - \eta t Y_1 \tag{2}$$

where, π is the total net profit, P is the unit price of the product, P is the total production of the product, *W* is the wage per unit labor force, *R* is the cost per unit capital, η represents the net carbon emission per unit production of Product 1, excluding carbon emission quota; and t means the unit price of carbon emission.

Let's assume that the production sector is perfectly competitive, and the zero profit condition can be achieved. The zero profit condition says that there is no barrier for enterprise to enter a production sector, and when there is profit in one sector, a lot of enterprises will enter the sector until the profit drops down to zero and the sector market reach equilibrium state. Let $\pi_1 = 0$, we obtain:

$$P_1 Y_1 - \eta t Y_1 = W L_1 + R K_1 \tag{3}$$

Let's discuss the marginal output of labor and capital under the zero profit condition. The marginal output of a production factor means the total benefit of investing in a single production factor. In other words, let's try to compute the increase in production (ΔY_1) by investing labor force (ΔL_1) or capital (ΔK_1).

Assuming the first order approximation between Y_1 and K_1, and manipulating the equation (3) by investing the capital ($Y_1 \rightarrow Y_1 + \Delta Y_1$, $K_1 \rightarrow K_1 + \Delta K_1$):

$$\Delta Y_1 = \frac{dY_1}{dK_1}\Delta K_1 = \frac{d(A_1 K_1^{\alpha} L_1^{1-\alpha})}{dK_1}\Delta K_1 = Y_1 \frac{\alpha}{K_1}\Delta K_1$$

$$P_1(Y_1 + \Delta Y_1) - \eta t(Y_1 + \Delta Y_1) = WL_1 + R(K_1 + \Delta K_1)$$

Solving the above equations, we can obtain that the marginal output of the capital is equal to its price as equation (4):

$$RK_1 = \alpha(P_1 - \eta t)Y_1 \tag{4}$$

Similarly, we can obtain the relationship for marginal output of labor force as equation (5):

$$WL_1 = (1-\alpha)(P_1 - \eta t)Y_1 \tag{5}$$

From equation (4-5), we can easily deduce the following equations to express capital and labor force as functions of production output and other related modelling parameters:

$$K_1 = \frac{\alpha}{R}(P_1 - \eta t)Y_1 \tag{6}$$

$$L_1 = \frac{(1-\alpha)}{W}(P_1 - \eta t)Y_1 \tag{7}$$

Substituting (6) and (7) into formula (1), the production output Y_1 can be canceled and we obtain the following relationship among modelling parameters:

$$P_1 - \eta t = \frac{1}{A_1}\left(\frac{R}{\alpha}\right)^{\alpha}\left(\frac{W}{1-\alpha}\right)^{1-\alpha} \tag{8}$$

3.2. Carbon reduction sector

The main role of the carbon reduction sector is to eliminate or reduce the carbon emissions generated by the production sector by producing products (i.e., Product 2 in our model). Following similar derivation procedure and assumptions as the production sector, the production function and profit function of the carbon reduction sector can be obtained as:

$$Y_2 = A_2 K_2^{\beta} L_2^{1-\beta} \tag{9}$$

$$\pi_2 = P_2Y_2 - WL_2 - RK_2 + \delta tY_2 \tag{10}$$

where, δ is the carbon offset credit generated by a unit Produced 2, excluding the carbon emission quota. Similar to the equation (4), (5), and (8), we can obtain the following relationship for the carbon reduction sector:

$$RK_2 = \beta(P_2 + \delta t)Y_2 \tag{11}$$

$$WL_2 = (1 - \beta)(P_2 + \delta t)Y_2 \tag{12}$$

$$P_2 + \delta t = \frac{1}{A_2}\left(\frac{R}{\beta}\right)^{\beta}\left(\frac{W}{1-\beta}\right)^{1-\beta} \tag{13}$$

3.3. Household sector

In this work, we are also interested in the social welfare. As a result, we need to analyze the total revenue of the household sector, which is defined as the total income of all possible sectors. In this work, the total revenue (*N*) can be computed by summing up the contributions from capital cost and labor force wage of all sectors. To simplify the derivation while not altering the conclusion, we further assume that $R_1 = R_2 = R$ and $K_1 = K_2 = K$.

$$N = RK + WL \tag{14}$$

$$K = K_1 + K_2 \tag{15}$$

$$L = L_1 + L_2 \tag{16}$$

By substituting equations (4), (5), (11), (12), (15), and (16) into (14), the revenue can be expressed as function of production output and modelling parameters:

$$N = (P_1 - \eta t)Y_1 + (P_2 + \delta t)Y_2 \tag{17}$$

Considering the consumption of two products, the consumer's satisfactory can be evaluated using the utility function. In this work, we assume that the utility function satisfies the following form which is similar to the Cobb-Douglas equation:

$$U(Y_1, Y_2) = Y_1^{\lambda}Y_2^{1-\lambda}$$

where, λ is the weighting coefficient. Note that in this work, we also assumes that the social welfare can be represented by the consumer's utility function. To obtain the maximum social welfare, we maximize the utility function under the constraint that total price of products should be within the revenue budget of the household sector. Finally, the following constrained optimization problem can be obtained:

$$max_{[Y_1,Y_2]}: U(Y_1,Y_2), \quad \text{subject to } P_1Y_1 + P_2Y_2 \le N$$

To solve the constrained maximization problem, the popular Lagrange multiplier method is employed and the following Lagrange augmented function is formulated:

$$L(Y_1,Y_2,\varepsilon) = U(Y_1,Y_2) + \varepsilon\,(P_1Y_1 + P_2Y_2 - N)$$

where, ε is the coefficient. Since the utility function $U(Y_1,Y_2)$ is a concave function and the maxima can be obtained by solving the stagnation point using the following first-order derivatives' equation:

$$\frac{\partial L(Y_1,Y_2,\varepsilon)}{\partial Y_1} = 0: \qquad \lambda\frac{Y_1^{\lambda-1}}{Y_2^{\lambda-1}} + \varepsilon\,P_1 = 0$$
$$\frac{\partial L(Y_1,Y_2,\varepsilon)}{\partial Y_2} = 0: \qquad (1-\lambda)\frac{Y_1^{\lambda}}{Y_2^{\lambda}} + \varepsilon\,P_2 = 0$$
$$constraint: \qquad P_1Y_1 + P_2Y_2 - N = 0$$

The above equations can be easily solved. The following relationship representing the division of total revenue into total costs of Product 1 and Product 2 can be established:

$$P_1Y_1 = \lambda N \tag{18}$$

$$P_2Y_2 = (1-\lambda)N \tag{19}$$

To further eliminate *N*, the condition of the carbon market clearance can be used. When the carbon emission from producing Product 1 equals to the carbon reduction from producing Product 2, the carbon clearance condition is achieved:

$$\delta Y_2 = \eta Y_1 \tag{20}$$

Considering the equilibrium condition and substituting equation (14) into (18) and (19):

$$P_1Y_1 = \lambda(RK + WL) \tag{21}$$

$$P_2Y_2 = (1-\lambda)(RK + WL) \tag{22}$$

From equations (5), (12), (16), (20), (21) and (22), eliminating the production outputs (Y_1 and Y_2), the following relationship can be obtained:

$$(1-\alpha)\lambda\left(\frac{R}{W}\frac{K}{L}+1\right)\left(1-\frac{\eta t}{P_1}\right) + (1-\beta)\lambda\frac{\eta}{\delta}\left(\frac{R}{W}\frac{K}{L}+1\right)\left(\frac{(1-\lambda)\delta}{\lambda\eta}+\frac{\delta t}{P_1}\right) = 1 \tag{23}$$

From equation (23) and let $\theta = {1}/{(\lambda\eta(\alpha-\beta))}$, $\tau = {\left((1-\alpha) + \frac{(1-\beta)(1-\lambda)}{\lambda}\right)}/{(\alpha\eta - \beta\eta)}$, we get equation (24) through mathematical manipulation:

$$\frac{R}{W} = \frac{\theta}{\tau + \frac{t}{P_1}} - \frac{L}{K} \tag{24}$$

Normalizing *R* to 1:

$$W = \frac{\tau + \frac{t}{P_1}}{\theta - \frac{L}{K}\left(\tau + \frac{t}{P_1}\right)} \tag{25}$$

$$R = 1 \tag{26}$$

It can be found that when the total labor and the total capital are given, the return on labor is positively correlated to ${}^{t}/_{P_1}$.

By substituting equation (25) and (26) into (8):

$$P_1 - \eta t = \frac{1}{A_1}\left(\frac{1}{\alpha}\right)^{\alpha}\left(\frac{1}{1-\alpha}\frac{\tau + \frac{t}{P_1}}{\theta - \frac{L}{K}\left(\tau + \frac{t}{P_1}\right)}\right)^{1-\alpha} \tag{27}$$

Finally, the relation between the output P_1 and the carbon emission unit price *t* can be expressed as:

$$P_1 = \frac{1}{A_1}\left(\frac{1}{\alpha}\right)^{\alpha}\left(\frac{1}{1-\alpha}\frac{\tau + \frac{t}{P_1}}{\theta - \frac{L}{K}\left(\tau + \frac{t}{P_1}\right)}\right)^{1-\alpha} + \eta t \tag{28}$$

Similarly, consider (13), (20), (25) and (26) to get the relation of P_2 and *t* as the following:

$$P_2 = \frac{1}{A_2}\left(\frac{1}{\beta}\right)^{\beta}\left(\left(\frac{1}{\theta}\tau + \frac{1}{\theta}\frac{t}{P_1}\right)\Big/(1-\beta)\right)^{1-\beta} - \delta t \tag{29}$$

Combining equation (20), (21) and (22), the ratio of Y_1/Y_1 can be evaluated as:

$${}^{Y_1}/_{Y_2} = {}^{\delta}/_{\eta} = \frac{\lambda}{1-\lambda}\frac{P_2}{P_1}$$

Thus we obtain the following relation:

$$\delta(1-\lambda)\, P_1 - \eta\lambda P_2 = 0 \tag{30}$$

Finally, combining equations (25), (28), (29) and (30), the target set of equations can be obtained as the following equation (31). In equation (31), there are four unknowns and four independent equations, and the solution of $[P_1, P_2, W, t]$ can be solved for each given set of modelling parameters $[\ A, B, \alpha, \beta, \eta, \delta, \lambda,\ {}^{K}/_{L}]$. Note that *R* has been normalized into unity.

$$
\begin{aligned}
f_1(P_1, W, t) &= W - \frac{\tau + \frac{t}{P_1}}{\theta - \frac{L}{K}\left(\tau + \frac{t}{P_1}\right)} = 0 \\
f_2(P_1, W, t) &= P_1 - \frac{1}{A_1}\left(\frac{1}{\alpha}\right)^{\alpha}\left(\frac{1}{1-\alpha}\frac{\tau + \frac{t}{P_1}}{\theta - \frac{L}{K}\left(\tau + \frac{t}{P_1}\right)}\right)^{1-\alpha} - \eta t = 0 \\
f_3(P_2, W, t) &= P_2 - \frac{1}{A_2}\left(\frac{1}{\beta}\right)^{\beta}\left(\left(\frac{1}{\theta}\tau + \frac{1}{\theta}\frac{t}{P_1}\right)\Big/(1-\beta)\right)^{1-\beta} + \delta t = 0 \\
f_4(P_1, P_2) &= \delta(1-\lambda)\, P_1 - \eta\lambda P_2 = 0
\end{aligned} \qquad (31)
$$

3.4. Numerical Simulations

In the numerical simulation, Equation (31) can be solved to get the equilibrium unit carbon reduction price t, equilibrium price of Product 1 (P_1), Product 2 (P_2), and wage W. If we put the solution into (21) and (22), we can get the balanced output of Product 1 (Y_1) and Product 2 (Y_2). Numerical simulation is performed using MATLAB (The MathWorks, Inc., 2024), and the equation (31) is solved using the MATLAB internal solver *fsolve*. The coding flowchart is straightforward and is shown in Figure 1.

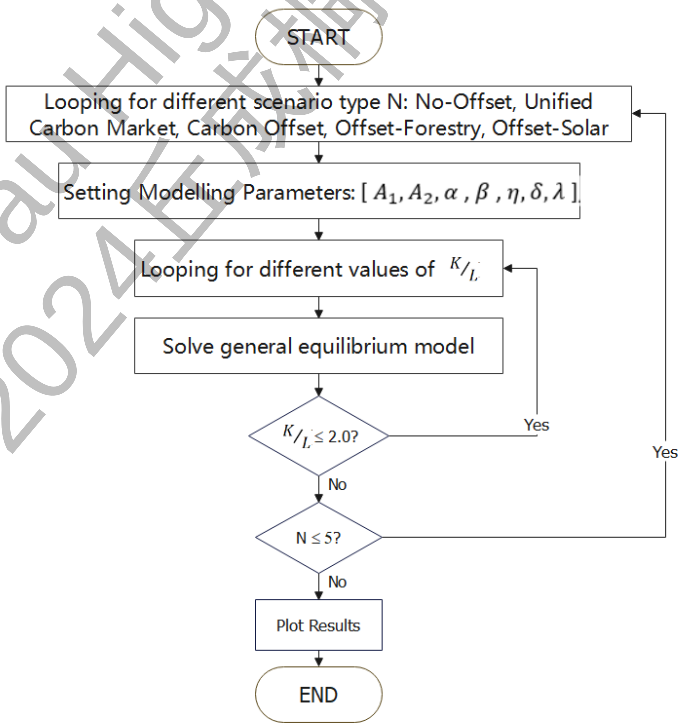


Figure 1 Coding flowchart for closed Economy described in general equilibrium model.

As shown in Figure 1, five types of scenarios are considered: no carbon offset mechanism, with carbon offset mechanism, unified carbon market, forestry carbon reduction, and solar carbon reduction. The scenarios' set-up is shown below in Table 1.

Table 1: Configurations of four types of scenarios.

Scenario 1: no carbon offset mechanism	$A_1 = 1.0, A_2 = 1.0, \alpha = 0.7, \beta = 0.3, \eta = 0.0, \delta = 0.0, \lambda = 0.8$
Scenario 2: with carbon offset mechanism	$A_1 = 1.0, A_2 = 1.0, \alpha = 0.7, \beta = 0.3, \eta = 0.3, \delta = 0.4, \lambda = 0.8$
Scenario 3: unified carbon (t as a constant value) market	$A_1 = 1.0, A_2 = 1.0, \alpha = 0.7, \beta = 0.7, t = 2.0, \lambda = 0.8$
Scenario 4: forestry carbon reduction	$A_1 = 1.0, A_2 = 1.0, \alpha = 0.7, \beta = 0.3, \eta = 0.3, \delta = 0.1, \lambda = 0.6$
Scenario 5: solar energy carbon reduction	$A_1 = 1.0, A_2 = 1.0, \alpha = 0.7, \beta = 0.8, \eta = 0.3, \delta = 0.5, \lambda = 0.9$

Proposition 1: Compared with the unified carbon market without any carbon pricing consideration, the total social welfare increases after the introduction of carbon offset mechanism.

Without the introduction of the carbon offset mechanism, the output of sector 2 can only provide goods for consumers, but cannot reduce carbon for sector 1. This increases social friction and makes it more difficult to achieve the optimal allocation of society. The social welfare is assumed to be the summation of the income of all individuals in a society. With this assumption, the social welfare is equal to the utility function $U(Y_1, Y_2)$, and represents the overall welfare level of the society.

The impact of the carbon offset mechanism on social welfare is being investigated. Figure 2 shows the comparison of social welfare evaluated under scenarios of no carbon emission limit (Scenario 1) and with carbon offset mechanism (Scenario 2). By manually setting $\eta = 0.0, \delta = 0.0$, the impact of carbon emission and capture is ignored. It can be seen that the introduction of carbon offset mechanism will reduce social welfare compared to the scenario when there is no limit on carbon credit thus the environmental loss is not accounted for.

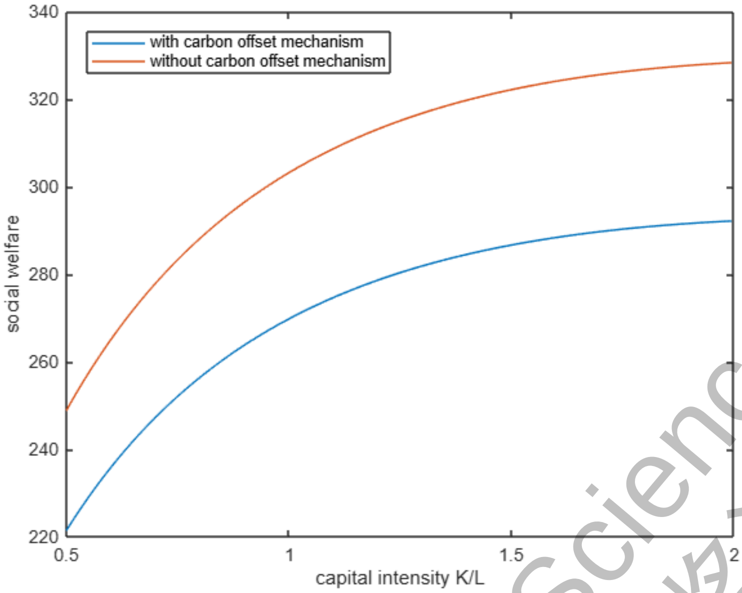


Figure 2 Comparison of social welfare changes before and after the implementation of carbon emission restriction.

The impact of directly purchasing carbon credit from a unified carbon market on social welfare is investigated. After the unit price of carbon emission is given, the carbon emission of industrial sector 1 is offset by the purchase of external carbon quotas. Figure 3 demonstrates that, with a carbon offset mechanism (Scenario 2) in place, total social welfare is higher than that when carbon credits are purchased on the carbon market with a unified price (Scenario 3). Note that when modelling the scenario of carbon market, the unit price of the carbon is assumed to be a constant value of $t = 2.0$ instead of obtained by solving equation (31).

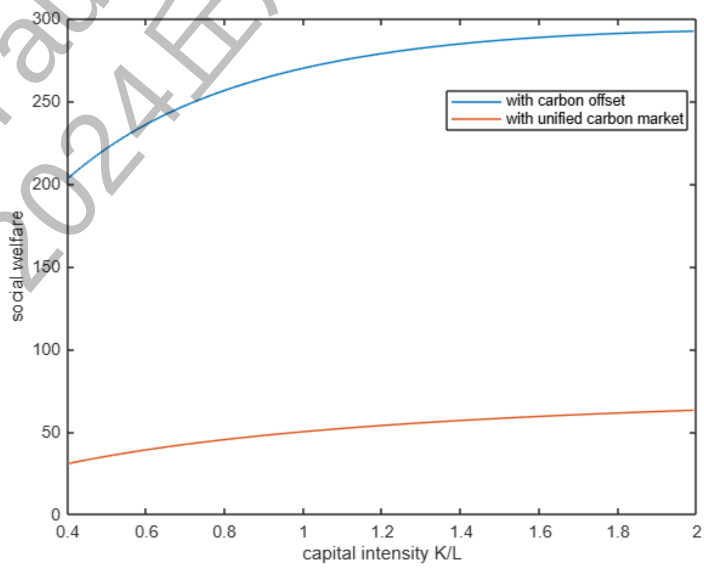


Figure 3. Comparison of the social welfare of the carbon offset mechanism and that when carbon credits are purchased from carbon market with a unified price.

The impact of using different carbon capturing technology as carbon offset mechanism is investigated, with the goal to understand the selection of carbon offset mechanisms for different regions of various resources endorsement. Forestry carbon reduction and solar carbon reduction are taken as representations of carbon reduction technologies. Figure 4 illustrates results when forestry carbon reduction is implemented as carbon offset mechanism, the output of Product 1 can be obtained numerically with respect to capital intensity.

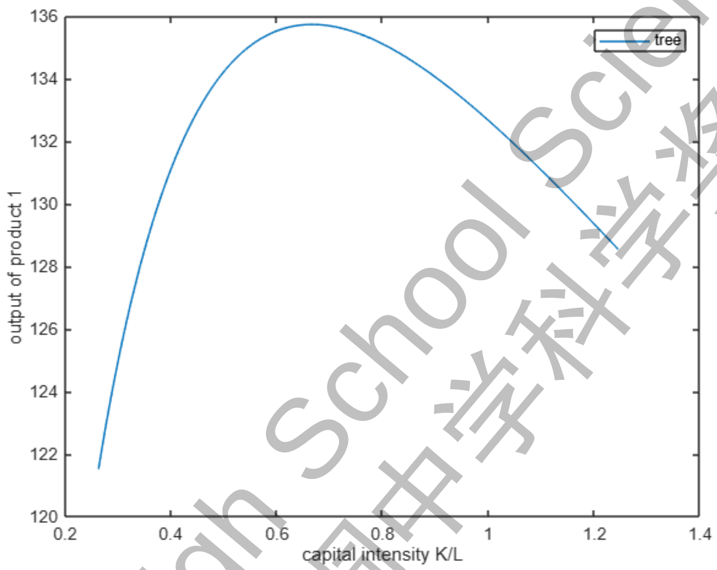
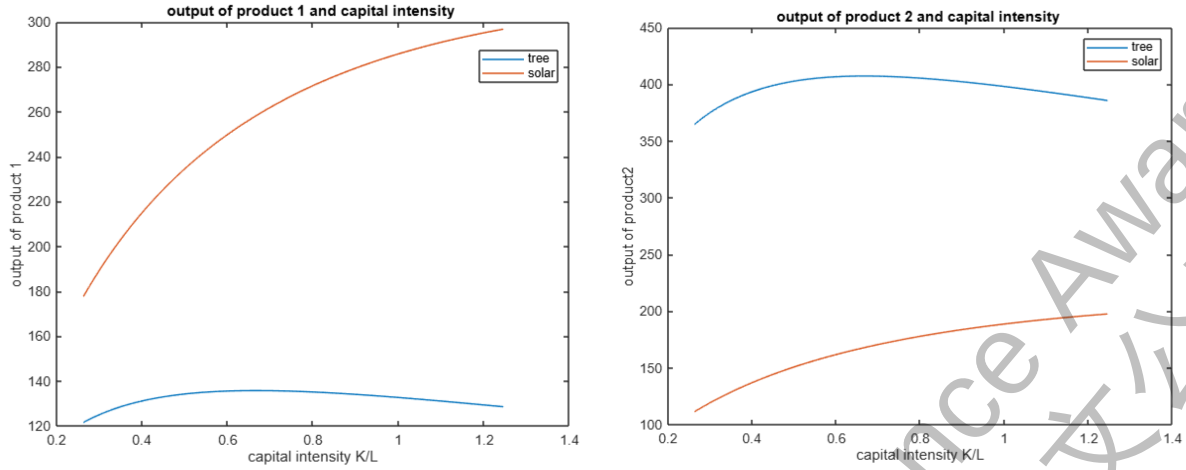


Figure 4. Changes of product output with respect to capital intensity under forestry carbon reduction.

The investigation also compares the outcomes of employing a variety of carbon capture technologies as the carbon offset mechanism. It can be seen that with the increase of capital/labor ratio, social welfare firstly increases and then decreases. This is because forestry carbon reduction is more labor intensive than capital intensity. When the amount of capital is small, increasing the K/L ratio will improve the efficiency of carbon reduction and stimulate the output of industrial sector 1, thus reducing the overall social efficiency. Secondly, we consider options for different models of carbon reduction, such as forestry carbon reduction versus solar carbon reduction, and see which approach achieves greater social efficiency at different ratios of capital/labor endowments.



(a) (b)

Figure 5. Changes in the output of products under different capital intensity with forestry carbon reduction and solar carbon reduction.

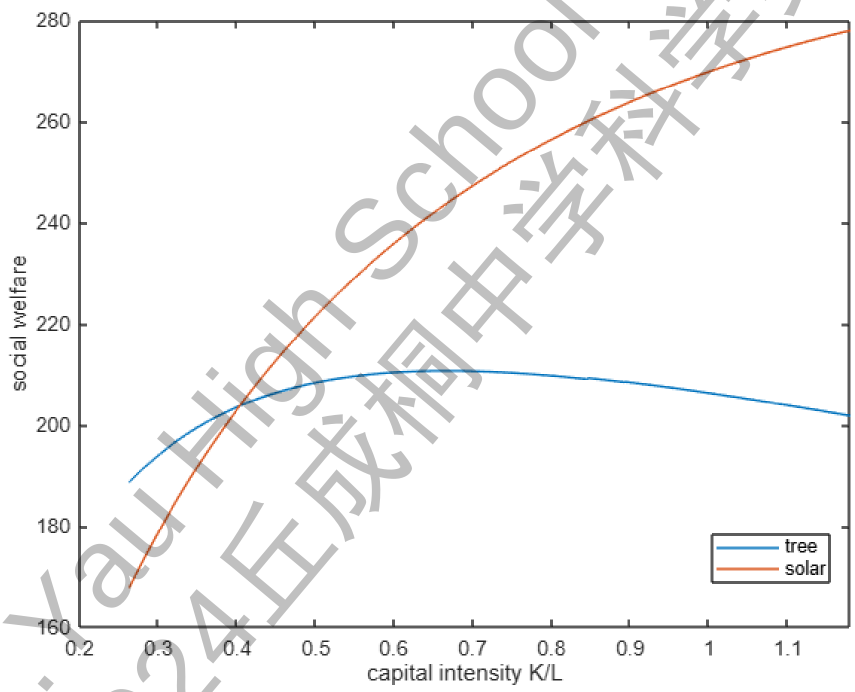


Figure 6. Comparison of social welfare between forestry carbon reduction and solar carbon reduction.

Figure 5 and Figure 6 respectively show the output and social welfare of each sector under different capital intensity (K/L) conditions. Firstly, it can be seen that when K/L is low, forestry carbon reduction, as a relatively labor-intensive carbon reduction method, can bring higher social welfare. When K/L is high, capital-intensive carbon reduction technology will greatly liberate the labor force, improving carbon reduction efficiency, and increase total social welfare. Secondly, it can also be seen that the output of industrial product 1 under the carbon reduction of labor-intensive forestry technology is always lower than that under the carbon reduction of the capital-intensive solar technology, even though with the fact that the output of forestry product is higher than the output of solar product.

Compared to the scenario of directly purchasing carbon credit from carbon market, if the carbon emission price is high, or the economy is labor-intensive with human resources to engage in carbon reduction (such as forestry), the adoption of carbon offset mechanism (such as forestry carbon reduction) will be superior to the direct purchase of carbon credits. Conversely, in an exogenous carbon market where the price of carbon credit is low, or in an economy where capital intensity is high, it may be better to buy credits directly.

4. Two-country extension models

We have discussed how different carbon offset mechanism technologies behaved and direct carbon credit purchase under the general equilibrium model of closed economy in chapter 3. In the extension model in this chapter, we will construct a two-country model of international trade and discuss the effects of international tariffs between two economies.

Between two economies A and B, labor and capital cannot flow across country borders, but Products 1 and 2 can flow across borders through international trade. Assuming that the tariff rates of product 1 and product 2 is ω_1 and ω_2, respectively. In terms of carbon reduction, economy A adopts a carbon offset mechanism, while economy B does not consider the negative effects of carbon emissions and does not have a carbon offset mechanism. It is assumed that the consumer's utility function is in the same form for both economies. The optimization problem facing each production sector of the two economies is set up as the following section 4.1 and 4.2.

4.1. Open economy A model

Assuming that a carbon offset mechanism has been adopted to take into account the negative effects of carbon emissions. Similar to the general equilibrium model, the production of sector 1 in Economy A can be expressed as:

$$Y_1^A = A_1 K_{1A}^{\alpha} L_{1A}^{1-\alpha} \tag{32}$$

The profit function is:

$$\pi_1^A = P_{1A}^I Y_{1A}^I + P_{1A}^E Y_{1A}^E - WL_{1A} - RK_{1A} - \eta t Y_1^A \tag{33}$$

where, Y_{1A}^{I} is the domestic sales volume of Product 1, and Y_{1A}^{E} is the export volume of product 1 from Economy A to Economy B. The total production of Product 1 in Economy A can be assumed in the following form:

$$Y_1^A = Y_{1A}^I + Y_{1A}^E \tag{34}$$

To maximize the profit, the price of domestic sale and export sale should be the same. Similar to the analysis in general equilibrium model, the marginal output of labor and capital can be expressed as the following equations:

$$P_{1A}^I = P_{1A}^E = P_{1A} \tag{35}$$

$$RK_{1A} = \alpha(P_{1A} - \eta t)Y_1^A \tag{36}$$

$$WL_{1A} = (1-\alpha)(P_{1A} - \eta t)Y_1^A \tag{37}$$

Similarly, for Product sector 2:

$$Y_2^A = A_2 K_{2A}^{\beta} L_{2A}^{1-\beta} \tag{38}$$

The profit function is:

$$\pi_2^A = P_{2A}^I Y_{2A}^I + P_{2A}^E Y_{2A}^E - WL_{2A} - RK_{2A} + \delta t Y_2^A \tag{39}$$

where, Y_{2A}^{I} is the domestic sales volume of product 2, Y_{2A}^{E} is the export volume of product 2, which satisfies:

$$Y_2^A = Y_{2A}^I + Y_{2A}^E \tag{40}$$

Similar to the analysis of product sector 1, the following set of equations can be established:

$$P_{2A}^I = P_{2A}^E = P_{2A} \tag{41}$$

$$RK_{2A} = \beta(P_{2A} + \delta t)Y_2^A \tag{42}$$

$$WL_{2A} = (1-\beta)(P_{2A} + \delta t)Y_2^A \tag{43}$$

The labor and capital allocation of Economy A is:

$$L_A = L_{1A} + L_{2A} \tag{44}$$

$$K_A = K_{1A} + K_{2A} \tag{45}$$

Maximizing the consumers' satisfaction in Economy A by maximizing its utility function, we obtain:

$$P_{1A}^I Y_{1A}^I + P_{1A}^I Y_{1B}^E = \lambda N \tag{46}$$

$$P^I_{2A}Y^I_{2A} + P^I_{2A}Y^E_{2B} = (1-\lambda)N \quad (47)$$

where N is the total income of the household sector, and can be expressed as the following taking into account the tax income as well:

$$N = R_AK_A + W_AL_A + T_A \quad (48)$$

where, T_A is the tariffs imposed by Economy A.

4.2. Open economy B model

Assuming there is no carbon offset mechanism in Economy B, regardless of the impact of carbon emissions on the environment. In this case, for the Product sector 1:

$$Y^B_1 = B_1K^{\alpha}_{1B}L^{1-\alpha}_{1B} \quad (49)$$

Removing the amount introduced by carbon price from the model of Economy A, we obtain the profit function of Economy B as:

$$\pi^B_1 = P^I_{1B}Y^I_{1B} + P^E_{1B}Y^E_{1B} - WL_{1B} - RK_{1B} \quad (50)$$

where, Y^I_{1B} is the domestic sales volume of product 1 produced by Economy B and Y^E_{1B} the export volume of product 1 produced by Economy B. The total volume of product 1 can be computed as Y^B_1 as:

$$Y^B_1 = Y^I_{1B} + Y^E_{1B} \quad (51)$$

For Product sector 2:

$$Y^B_2 = A_2K^{\beta}_{2B}L^{1-\beta}_{2B} \quad (52)$$

The corresponding profit function is:

$$\pi^B_2 = P^I_{2B}Y^I_{2B} + P^E_{2B}Y^E_{2B} - WL_{2B} - RK_{2B} \quad (53)$$

where, Y^I_{2B} is the domestic sales volume of product 2, Y^E_{2B} is the export volume of product 2, satisfying:

$$Y^B_2 = Y^I_{2B} + Y^E_{2B} \quad (54)$$

The labor and capital allocation of Economy B is:

$$L_B = L_{1B} + L_{2B} \quad (55)$$

$$K_B = K_{1B} + K_{2B} \quad (56)$$

By maximizing the utility function, the consumer's satisfaction in Economy B can be found as:

$$P_{1B}^{I}Y_{1B}^{I} + P_{1B}^{I}Y_{1A}^{E} = \lambda N \tag{57}$$

$$P_{2B}^{I}Y_{2B}^{I} + P_{2B}^{I}Y_{2A}^{E} = (1-\lambda)N \tag{58}$$

while:

$$N = R_B K_B + W_B L_B + T_B \tag{59}$$

T_B is the tariffs imposed by Economy B.

4.3. Effect of international trade tariffs

Assume that labor resource endowments in Economy A are capital-intensive and suitable for the production of Product 1, and labor resource endowments in Economy B is labor-intensive and suitable for the production of Product 2. The tariff rate for product 1 and product 2 is assumed to be ω_1 and ω_2, respectively.

The relationship of product price and tariff rate can be established. The domestic sale price of Product 1 in Economy A, increased by the tariff, is equal to the domestic sale price of Product 1 in Economy B. The tax income can be evaluated by the domestic sale price multiplied by the tax rate. As a result, we obtain the following relationships:

$$P_{1B}^{I} = (1+\omega_{1AB})P_{1A}^{E} \tag{60}$$

$$P_{2A}^{I} = (1+\omega_{2BA})P_{2B}^{E} \tag{61}$$

$$T_A = (P_{2A}^{I} - P_{2B}^{I})Y_{2A}^{E} = P_{2B}^{I}\omega_2 Y_{2A}^{E} \tag{62}$$

$$T_B = (P_{1B}^{I} - P_{1A}^{E})Y_{1A}^{E} = P_{1A}^{I}\omega_1 Y_{1A}^{E} \tag{63}$$

Considering the models established for Economy A and B, the international trade model can be established as:

$$(1-\alpha)(P_{1A}-\eta t)\lambda(R_1K_1 + W_1L_1 + P_{1A}\omega_1 Y_{1A}^{E})\frac{1}{P_{1A}} + (1-\beta)(P_{2A}+\delta t)(1-\lambda)(R_1K_1 + W_1L_1 + P_{1A}\omega_1 Y_{1A}^{E})\frac{1}{P_{1B}} - W_1L_1 = 0 \tag{64}$$

$$P_{1A} - \eta t - \frac{1}{A}(\frac{R_1}{\alpha})^{\alpha}(\frac{W_1}{1-\alpha})^{1-\alpha} = 0 \tag{65}$$

$$P_{1B} + \delta t - \frac{1}{B}(\frac{R_1}{\beta})^{\beta}(\frac{W_1}{1-\beta})^{1-\beta} = 0 \tag{66}$$

$$\eta((R_1K_1 + W_1L_1 + P_{1A}\omega_1Y_{1A}^E)\frac{1}{P_{1A}} + Y_{1A}^E) - \delta((R_1K_1 + W_1L_1 + P_{1A}\omega_1Y_{1A}^E)\frac{1}{P_{1A}} - Y_{2A}^E) = 0 \tag{67}$$

$$(1-\alpha)\lambda(R_2K_2 + W_2L_2 + P_{2B}\omega_2Y_{2A}^E) + (1-\beta)(1-\lambda)(R_2K_2 + W_2L_2 + P_{2B}\omega_2Y_{2A}^E) - W_2L_2 = 0 \tag{68}$$

$$P_{2A} - \frac{1}{A}(\frac{R_2}{\alpha})^{\alpha}(\frac{W_2}{1-\alpha})^{1-\alpha} = 0 \tag{69}$$

$$P_{2B} - \frac{1}{B}(\frac{R_2}{\beta})^{\beta}(\frac{W_2}{1-\beta})^{1-\beta} = 0 \tag{70}$$

$$P_{2A} - (1+\omega_1)P_{1A} = 0 \tag{71}$$

$$P_{1B} - (1+\omega_2)P_{2B} = 0 \tag{72}$$

$$P_{1A}Y_{1A}^E = P_{2B}Y_{2B}^E \tag{73}$$

In the absence of a carbon offset mechanism, under the equilibrium condition, it is observed that one of the two economies, A or B, exports products with comparative advantages to the other economy. Based on the labor and capital endowment structure of the two economics ($\frac{K_A}{L_A}, \frac{K_B}{L_B}$) and the relative capital intensity of the two industries (α and β), the introduction of carbon offset mechanism and carbon emission reduction will have a regulatory effect on the two industries, and will also affect the comparative advantages of the two economies. The appearance of tariffs will regulate the trade between the two economies, such as the protection of national industries with carbon emission reduction by different tariffs. In this case, how to adjust the tariff rate to ensure the optimal situation of the society welfare depends on the relative resources endowments, carbon emission intensity, and carbon reduction efforts of the two economics. Our conclusion can be summarized as the following proposition.

Proposition: Considering the international trade of two economies, when Economy A adopts the carbon offset mechanism and Economy B does not adopt the carbon offset mechanism, under the equilibrium state, the two economies will respectively export the products with their comparative advantages. In other words, Economy A will produce more carbon reduction products for export, Economy B will produce more generic products for export.

We further analyze the relationship between tariff rate, trade volume and carbon reduction level. We perform a total differentiation of Equation (67), and the derivative of Product 1 output in Economy A with respect to the international tariff rate can be obtained:

$$\frac{\partial Y_{1A}^E}{\partial \omega_1} = \frac{(\delta - \eta)Y_{1A}^E}{1 + (\eta - \delta)\omega_1} \tag{74}$$

where, δ is the ability of product 2 to absorb carbon emissions, and η is the amount of carbon emitted per unit Product 1, excluding the emission quota.

The sigh (positive or negative) of the above formula depends on the magnitude of $(\delta - \eta)$ and ω_1. When the amount of carbon reduction per unit Product 2 is lower than the amount of carbon emitted by the industrial sector Product 1, we can obtain $\delta - \eta < 0$ and $\frac{\partial Y_{1A}^E}{\partial \omega_1} < 0$. This is also consistent with our common sense that when the tariff rate of product 1 rises, the export of product 1 will decline.

If the carbon reduction per unit of Product 2 exceeds the carbon emission of industrial sector Product 1, resulting in a numerator greater than 0 ($\delta - \eta > 0$), then the denominator will also be greater than 0 when the value of ω_1 is small. This indicates that when Economy A has high carbon reduction efficiency, increasing the tax rate of Economy A's product exporting (Product 1) to Economy B may increase the export volume. This is because when Economy A has a high carbon reduction efficiency, its product 2 is mainly used for carbon offset. As the tax rate of product 1 increases, the output of domestic product 2 produced for the purpose of carbon reduction decreases, and the demand for Economy B's product 2 increases. Accordingly, the production of product 1 in Economy B decreases, and the demand for product 1 in Economy A increases. Under the equilibrium condition, it can be seen that in the absence of carbon offset mechanism, Economy A and B exports products with comparative advantages to the other country.

Finally, we analyze the relationship between tariff ω_2 and trade volume Y_{2A}^E, which can be obtained by total differentiation of Equation (68):

$$\left((1-\alpha)\lambda\frac{P_{2B}}{P_{1B}}\omega_2 + (1-\beta)(1-\lambda)\omega_2\right)\frac{\partial Y_{2A}^E}{\partial \omega_2} = -(1-\alpha)\lambda\frac{P_{2B}}{P_{1B}}\, Y_{2A}^E \tag{75}$$

According to the equation provided, $\frac{\partial Y_{2A}^E}{\partial \omega 2}<0$, indicating that as the tariff rate on product 2 increases, the export of product 2 declines, and conversely, when the tariff rate decreases, the export of product 2 increases. This suggests that within the labor-intensive industries sector 2, a rise in export tax rate from Economy B, which has abundant labor and no carbon reduction mechanism, to Economy A, which has ample capital and a carbon reduction mechanism, will lead to a decrease in export volume. This is because the domestic demand for product 2 cannot be compensated by carbon offset mechanism.

The relationship between the tariff rate and the carbon reduction amount can be more precisely summarized as follows: the carbon reduction amount is proportional to the output of Product 2. We can see that when the export tax rate ω_2 increases, the import dependence of Product 2 of Economy A decreases, the output of domestic Product 2 increases, and the carbon reduction amount increases in equilibrium, which is conducive to the carbon reduction of Economy A. When the tariff rate rises and if the carbon reduction capacity of Product 2 in Economy A is lower than the carbon emission level produced by Product 1, the output of Product 1 in Economy A may decline, the carbon reduction volume decreases, and the emissions of Economy A also decreases. In Economy A, should Product 2's carbon reduction capability surpass the carbon emissions generated by Product 1, the increase in carbon emissions is counterbalanced by an equivalent rise in carbon reduction, thereby maintaining a dynamic equilibrium within the economy's carbon footprint.

5. Conclusion

To discuss the spatial and economic effects of inter-regional carbon tariff cooperation, the paper firstly constructs a general equilibrium model, and discusses how governments should design sector-specific tax rates and subsidy policies to internalize the negative externality of carbon emissions across sectors, correcting market failures that lead to social welfare losses. Secondly, we apply numerical simulation methods to guide regions with different resource endowments, industrial structures and capital intensity to choose the optimal carbon reduction pathway. Our research reveals that for closed economies, implementing carbon offset mechanism can improve market efficiency, which in turn increases the total social welfare.

In an open economy, when two economies can trade with each other and adopt their own carbon reduction strategies, our study indicates that economies with carbon offsets are more likely to develop greener industrial structures, while economies without carbon offsets are more likely to formulate general industrial structures. This suggests that trade, through inter-regional division of labor, brings about additional industrial redistribution effects, causing resource-rich countries to produce more carbon-intensive goods, amplifying the negative externality of emissions, thereby encouraging regions to impose corrective carbon tariffs. Additionally, from a societal perspective, imposing a certain level of consumption tax on conventional products or providing production subsidies for carbon offsetting products can assist in maximizing social welfare.

Our research offers theoretical guidance and recommendations for relevant policy-making. We emphasize that to elevate overall social welfare, governments should actively promote and enforce carbon offsetting systems while adjusting tax policies, such as levying consumption taxes on conventional products, to encourage the public to consume green products. Moreover, subsidies or tax benefits should be granted to enterprises producing carbon offsetting products to motivate the creation of more green goods, thereby promoting the green development of the entire economy. Simultaneously, international carbon cooperation should be advocated, green trade between different countries should be strengthened, and the challenge of global climate change should be jointly met.

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The seeds of this research originates from the global climate change and extreme weather events that have become increasingly pronounced in recent years. In line with the consensus of the Paris Agreement and China's "double carbon" targets, the central and local governments of China are actively formulating and implementing policies of carbon neutrality, aiming to facilitate an orderly transition of the economy and society towards low-carbon objective. The "Action Plan for Carbon Peaking Before 2030" released by the State Council stresses the development of strategies for developing green energy transformation, green and low-carbon technologies, carbon capture capabilities, and low carbon economic policy and market mechanisms. Given that China is of significant disparities in regional resources and economic development levels, the challenges associated with carbon reduction vary across regions. Each region must therefore drive green and low-carbon development in accordance with its specific conditions, scientifically formulate action plans, and select the optimal pathways for decarbonization. Strategies include choice of carbon pricing mechanisms (such as carbon taxes and carbon markets), negative emissions technologies (like ecological carbon sinks and CCUS), and clean energy technologies (such as wind and solar power), tailored to their particular circumstances.

Given the disparities in regional resource endowments and industrial structures, it is of significant importance and value to identify a scientific method that guides regions in formulating their distinct carbon peaking paths. This method should involve optimizing the design of carbon offset mechanisms to enhance social welfare and balancing costs and benefits. It should also take a comprehensive consideration of resources and structures to select the most suitable carbon reduction pathways. Additionally, it is essential to account for international trade policies, sector-level tax and subsidy policies, to achieve the optimal goal under the international trade system.

The author's belief in robust and inclusive finance as a transformative tool for societal and industrial development laid the foundation for an interdisciplinary exploration. The author also maintains a significant interest in environmental and energy issues, politics, and humanities, with a long-standing commitment to these fields. Through extensive learning and consultation with experts at the forefront of carbon market research, energy industry professors and senior engineers, national policy researchers, and high school teachers, as well as extensive reading and investigation, the author proposes that economic and financial modeling can be utilized to study the formulation of regional distinct low-carbon policies. This approach can simultaneously achieve the overarching goal of carbon reduction and environmental protection while promoting the growth of a low-carbon economy and overall social welfare. With the above-mentioned background and motivation, the author finally decided the topic of this paper: Design of Optimal Government Carbon Offsetting Mechanism: a Theory Based on Regional and Industry Perspectives.

The author is the sole author of the paper, and has undertaken all tasks of the paper. **Conceptualization**: The author has difficulties at the beginning in finding a good topic. Through extensive consultations and discussions with experts from various fields, including carbon market specialists, senior engineers and professors from the energy industry, national policy researchers, and high school teachers who are all on the frontlines of industrial and scientific research, the author finally decided the topic. The conceptualization process also allowed a deep understanding of related knowledge and background, ensuring that the paper is both academically rigorous and practically useful. **Literature Review**: The author of this paper conducted a thorough search on academic platforms such as China National Knowledge Infrastructure (CNKI) at https://www.cnki.net/ and Elsevier's ScienceDirect at

https://www.sciencedirect.com/. This extensive search yielded a substantial number of previous research findings concerning the establishment of carbon markets and carbon offset mechanisms. The author selectively read and summarized papers that are closely related to the topic of the paper. This process was instrumental in gathering a comprehensive understanding of the existing knowledge in the field, enabling the author to identify gaps, trends, and critical insights that informed the development of the paper's focus. **Theoretical Model and Formula Derivation**: The author had a hard time in modelling. Under the guidance of the advisors, the author learns a lot economic modelling knowledge and finally independently completed the establishment of the model and formula derivation. The theoretical model construction in this paper was primarily considered from three aspects: in terms of economic mathematical models, the modeling was based on the Cobb-Douglas form, zero-profit theorem, household income, and consumer utility functions; in terms of economic entity modeling, the paper established a general equilibrium model under a closed economy scenario as well as an extended model based on international trade under an open economy scenario; in terms of carbon offset mechanism modeling, the paper modeled and calculated social welfare under five different scenarios including no carbon constraints, a unified carbon market, a carbon offset mechanism using forestry, and a carbon offset mechanism using solar energy. **Data Analysis**: The author used MATLAB for modeling and simulation based on the theoretical model. The author encounter difficulties in numerical modeling in solving the Equation Sets. Eventually, the *fsolve* function built inside MATLAB is used to solve the established system of equations in a jointly manner. **Visualization and Analysis of Results**: Visualization of results was conducted using MATLAB. After numerically solving the theoretical model, datasets of social welfare and product output under different capital/labor endowment scenarios was obtained. The *plot* function in MATLAB was directly used to visualize the results.

The paper's development would not have been possible without the guidance of two esteemed advisors, Mr. Li Ruipeng and Mr. Huang Hualin. The two advisors involved in guiding this paper have no vested interests with the author, and their guidance was provided on a voluntary, unpaid basis. During the writing of the manuscript, Mr. Li Ruipeng offered significant guidance in the conceptualization, organization of the research work, refinement of content, imparting of foundational knowledge, and the analysis of the calculational data, as well as in the writing process. Mr. Huang Hualin provided valuable help in the conceptualization, knowledge of government policy making, assistance with data analysis and calculation, and guidance on the writing of the paper. The guidance of the advisors have played an important role in shaping the paper, and the author would like express her heartful gratitude.

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<tr><td>2014.9-2020.7</td><td colspan="5">广州市越秀区东风东路小学</td><td colspan="5">校纪检部部长、校国旗班升旗手、学习之星、文明之星、校合唱团主力等</td></tr>
<tr><td>2020.9-2024.9</td><td colspan="5">华南师范大学附属中学</td><td colspan="5">初中（奥班）、高中（奥班）/宣委、纪检、语文\美术科代表</td></tr>
<tr><td rowspan="2">学期成绩</td><td>语文</td><td>数学</td><td>英语</td><td>思想政治</td><td>地理</td><td>历史</td><td>物理</td><td>生物</td><td>体育与健康</td><td>研究学习</td></tr>
<tr><td>90</td><td>86</td><td>83</td><td>81</td><td>93.4</td><td>87</td><td>88</td><td>86</td><td>84</td><td>98</td></tr>
</table>

获奖记录

获奖记录	➢ 在第二十一届"叶圣陶杯全国中学生新作文大赛"总决赛二等奖； ➢ 在第二十一届"叶圣陶杯全国中学生新作文大赛"省级一等奖； ➢ 2022AMC10 考试一等奖（成绩前 5%，晋级 AIME）； ➢ 华南师范大学附属中学"自华杯"数学科三等奖； ➢ 第十四届"外教社杯"三等奖； ➢ 校奥班数学能力专项测试评估二等奖； ➢ 第 67 届校运会班徽设计初中组三等奖； ➢ 2023 学年第一学期"社会工作积极分子"称号；

	➢ 2023 学年第一学期“文明宿生”称号； ➢ 2023 学年第一学期“文明宿舍”成员奖； ➢ 2022 年“南都小记者”称号； ➢ “致经典”双语诵读会粤港澳大湾区初中组选拔赛三等奖。

证明材料


【编号 YSTB2024010121 】

全国中学生新作文大赛

获奖证书

卢雨可同学：

在第二十一届“叶圣陶杯”全国中学生新作文大赛中，你的作品《与“韵”共舟》荣获总决赛二等奖。

特发此证。

主办单位：中国当代文学研究会

批准文号：教育部教监管厅函〔2022〕13号

全国中学生新作文大赛组委会


【编号 YSTB20244184A3133 】

全国中学生新作文大赛

获奖证书

卢雨可 同学：

在第二十一届“叶圣陶杯”全国中学生新作文大赛中，你的作品《四笔成画》荣获省级一等奖。

特发此证。

主办单位：中国当代文学研究会

批准文号：教育部教监管厅函〔2022〕13号

全国中学生新作文大赛组委会


英语口语能力人工智能分级测评

CHIVOX NATIONAL SPOKEN ENGLISH TEST (CNSET)

等级认定证书

Certificate of Spoken English Proficiency

姓　　名：卢雨可

等　　级：五级B

熟练程度：基础（Basic）

证件号码：440106200809272441

证书编号：CNSET2312004536

2024年2月参加英语口语能力人工智能分级测评，通过五级B测评，特颁此证。

This is to certify that the bearer of this certificate has successfully taken and completed the Chivox National Spoken English Test in February, 2024.

中国信息协会

英语口语能力人工智能分级测评全国组织委员会

二〇二四年三月

英语口语能力人工智能分级测评计算机测评标准立项单位：中国信息协会（China Information Industry Association）

英语口语能力人工智能分级测评题库资源审定和授权单位：英国剑桥语言研究中心（Cambridge Language Research Centre, UK）

微信扫码验证


MAA AMC

American Mathematics Competitions

American Mathematics Competitions

CERTIFICATE OF DISTINCTION

is awarded to

Lu Yuke

for their superior performance on the

American Mathematics Competition

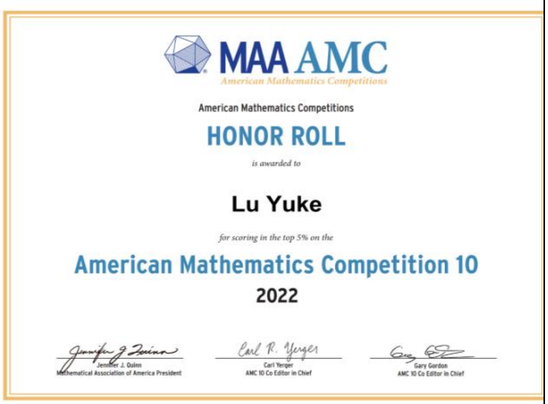
AND FOR QUALIFYING TO COMPETE IN THE AMERICAN INVITATIONAL MATHEMATICS EXAMINATION

2022

Jennifer J. Quinn, Mathematical Association of America President

Gary Gordon, AMC 10/12 Co Editor in Chief

Carl Yerger, AMC 10/12 Co Editor in Chief


MAA AMC

American Mathematics Competitions

American Mathematics Competitions

HONOR ROLL

is awarded to

Lu Yuke

for scoring in the top 5% on the

American Mathematics Competition 10

2022

Jennifer J. Quinn, Mathematical Association of America President

Carl Yerger, AMC 10 Co Editor in Chief

Gary Gordon, AMC 10 Co Editor in Chief

MAA AMC

American Mathematics Competitions

American Mathematics Competitions

CERTIFICATE

is awarded to

Lu Yuke

for participating on the

American Mathematics Competition 10

2022

Jennifer J. Quinn
Mathematical Association of America President

Carl Yerger
AMC 10 Co Editor in Chief

Gary Gordon
AMC 10 Co Editor in Chief

证 书

Certificate

卢雨可 同学在 2021—2022 学年第一学期初二奥班数学核心能力之因式分解专项评估中，获得 良好 等级，特此证明。

华南师范大学附属中学初中数学科组
初二奥班数学备课组
2021 年 10 月 28 日

编号：HFX202111205

获奖证书

Certificate of Award

初二3班 卢雨可 同学荣获我校2021-2022年度第一学期 首届“自华杯”初中数学低年级组三等奖 。

特发此证，以资鼓励。

扫一扫，查真伪

华南师范大学附属中学教学处
2022年02月14日

编号：HFZ202110178

获奖证书

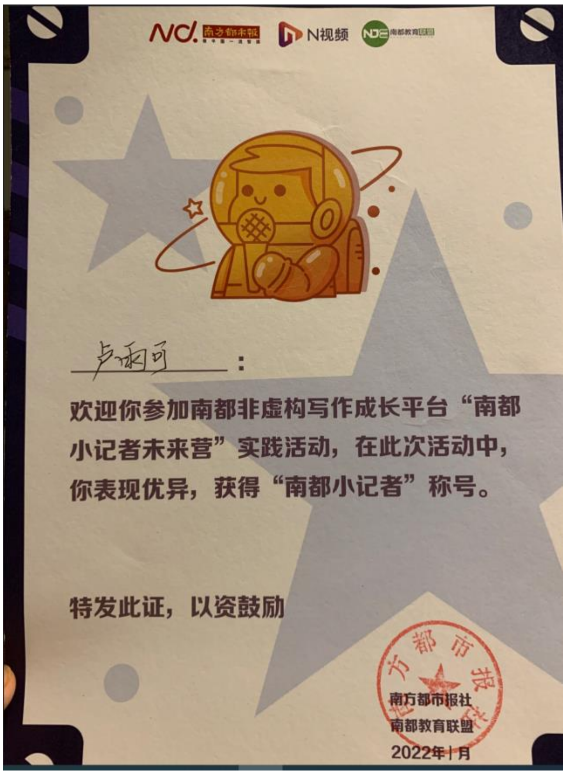
Certificate of Award

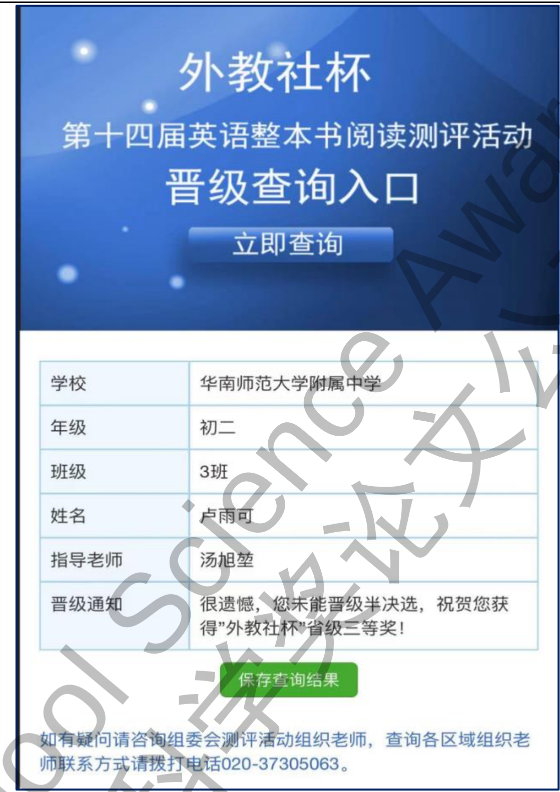
初二3班 卢雨可 同学荣获我校2021-2022年度第一学期 第67届校运会班徽设计评比初中组三等奖 。

特发此证，以资鼓励。

扫一扫，查真伪

共青团华南师大附中委员会
2021年10月26日





外教社杯

第十四届英语整本书阅读测评活动

晋级查询入口

立即查询

学校	华南师范大学附属中学
年级	初二
班级	3班
姓名	卢雨可
指导老师	汤旭堃
晋级通知	很遗憾，您未能晋级半决选，祝贺您获得"外教社杯"省级三等奖！

保存查询结果

如有疑问请咨询组委会测评活动组织老师，查询各区域组织老师联系方式请拨打电话020-37305063。

编号：HFW202010075

获奖证书

Certificate of Award

初一3班 卢雨可 同学荣获我校2020-2021年度第一学期 初一年级小歌手大赛二等奖 。

特发此证，以资鼓励。

扫一扫，查真伪

共青团华南师范大学附属中学委员会

2020年12月05日

广东省志愿服务时间证书

Voluntary Service Time Certificate of Guangdong Province

姓名/Name
卢雨可/YUKE LU
性别/Sex
女/F
证件类型/Type of ID
第二代居民身份证
身份证号码/ID Number
440106200809272441
注册日期/Register Date
2020年09月05日
注册地/Register Place
广东省广州市
服务时长/Service Time
103小时28分钟
（志愿服务时间明细附后）

一星志愿者

扫码查验服务记录 扫码参与服务记录

广东省志愿者联合会

2023年02月06日

证书编号/Certificate Number:Z544010620080927244I

开放查询地址/Open Query URL:www.izyz.org/zs

说明：该志愿者服务时长记录取自于广东青年大数据交互系统，由i志愿、志愿时、志愿深圳、江门义工、志愿中山等系统数据融合而成。如发现有不实记录，欢迎致电12355反映。


The Affiliated High School of South China Normal University

编号：HF202205469

获奖证书

Certificate of Award

初三3班卢雨可同学荣获我校2022-2023学年度第一学期"文明宿生"称号。

特发此证，以资鼓励。

华南师范大学附属中学

初中部学生处

2022年12月31日


The Affiliated High School of South China Normal University

编号：HF202205463

获奖证书

Certificate of Award

初三3班卢雨可同学荣获我校2022-2023学年度第一学期"文明宿舍"成员奖。

特发此证，以资鼓励。

华南师范大学附属中学

初中部学生处

2022年12月31日


The Affiliated High School of South China Normal University

编号：HF202208943

获奖证书

Certificate of Award

初三3班卢雨可同学荣获我校2022-2023学年度第一学期"社会工作积极分子"称号。

特发此证，以资鼓励。

华南师范大学附属中学

初中部学生处

2023年01月05日


志愿服务证明

Volunteer service certificate

卢雨可同学在华南师范大学附属中学就读期间，积极参加学校青年志愿者协会组织的志愿服务活动，工作认真负责，充分发扬志愿者精神，志愿服务时数总计为68.5学时。

参加的志愿服务活动项目主要有：

1、2022年06月28日　初中志愿服务　2.5小时
2、2022年06月07日　初中志愿服务　7.0小时
3、2021年12月17日　食堂值周　2.0小时
4、2021年12月07日　教学楼架空层、教室卫生保洁　3.0小时
5、2021年09月01日　第一学期校外志愿服务　10.0小时
6、2021年08月15日　第一学期校外志愿服务　10.0小时
7、2021年08月14日　第一学期校外志愿服务　5.0小时
8、2021年06月20日　2021第2学期校外志愿服务　9.0小时

特此证明。

共青团华南师大附中委员会

华南师大附中青年志愿者协会

2023年02月11日

黄华林个人简历

黄华林，男，广东省南雄市人，1982 年 4 月出生，2004 年 7 月毕业于华南师范大学思想政治教育，大学本科，正高级教师。现任华南师范大学附属中学教学处主任、信息资源中心主任。

现为华南师范大学兼职教授、硕士生校外导师，广州市中学政治教学研究会常务理事，广东教育学会中学思想政治课教学专业委员会常务理事，荣获南粤优秀教师称号、广州市“优秀教师”称号、广州市中学政治“十佳青年教师”称号，有四届荣获华南师大附中“最受学生欢迎的老师”金奖，曾获得首届广东省中小学青年教师教学能力大赛高中思想政治学科决赛一等奖、“广东省思想政治同课异构活动”一等奖、“广东省信息技术与时事、政治课程整合研究成果”一等奖，主持的项目曾获广东省教育教学成果奖（基础教育）二等奖、广东省中小学优秀德育科研成果一等奖，撰写案例入选教育部《“停课不停学”在线教学实践推进研究》优秀成果，参编出版了《微观经济学》和《劳动教育的乡村表达——高中“三同”劳动教育课程的建构与实践》，主持和参与了多个省市课题，多篇论文发表在《中学政治教学参考》、《教学月刊·中学版》、《中小学德育》和《中国校外教育》等刊物上。

简历

姓名　李瑞鹏

手机：18023016904
邮箱：47-148@gduf.edu.cn

✧ 基本信息：

最高学历：	博士	专业：	金融学
性别：	男	出生年月：	1986 年 9 月
民族：	汉族	政治面貌：	共产党员

✧ 教育背景：

2011/09—2016/07	博士研究生	专业：金融学 学校：清华大学经济管理学院
2009/09—2011/08	硕士研究生	专业：投资学 学校：中央财经大学
2005/09—2009/08	本科	专业：投资学 学校：中央财经大学

✧ 工作经历：

2016/08——2019/07　特聘副研究员
工作单位：中山大学国际金融学院

2019/08——至今　讲师（2023 年 硕士生导师）
工作单位：广东金融学院金融与投资学院

✧ 教学科研：

研究方向：公司金融，供应链金融，金融机构与市场
教授课程：金融学，金融风险管理，中央银行学
科研成果：近年在 SSCI 期刊发表文章 2 篇，主持国家自然科学基金青年项目和广东省自然科学基金各 1 项