Environmental and economic sustainability in pricing strategy of carbon tax: application of environmental Kuznets curve and real options approach

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Abstract. The issue of global warming has become one of the serious factors affecting sustainable economic development with the dynamics of economic development interact with carbon emissions. The pricing strategy for carbon tax is one of the most feasible methods to achieve the goal of "net zero" in carbon emissions. This paper mainly discusses how the government prices carbon tax without affecting the target profit of the firms. This paper combines the dynamic real options approach (ROA) and the environmental Kuznets curve (EKC) to construct an economic model for the government to levy carbon tax. This paper goals the government how to levy carbon tax on industry to accelerate industrial transformation. Assume that the uncertain changes in the growth of the industry are dependent on the carbon tax, and the changes follow the geometric Brownian motion when carbon emissions change, the government imposes different carbon taxes on industry in order to control carbon emissions within a reasonable range. If industry reduces carbon emissions, the government will also reduce carbon tax. The threshold is the upper limit of the government's carbon tax on industry. In order to accelerate the industry investment in innovative clean energy technology and equipment, the threshold provides a reference basis for the government to impose carbon tax on industry and achieve a win-win strategy for economic development and environmental protection.

1. Introduction

Tcvetkov mentioned that global warming is an existential threat to mankind, and a rapid energy transition is essential. This will be the decisive social, political and technological challenge facing the 21st century [1]. The carbon emissions generated in the industrial production process have significant negative externalities to the environment and there is a high correlation with climate change. The Intergovernmental Panel on Climate Change (IPCC) report proposes that net carbon emissions must reach “net zero” in 2050. This paper mainly discusses how the government can impose a carbon tax on firms without affecting their target profits. Therefore, this paper will focus on the issue of environmental pollution taxes. Using the hypothesis of the environmental Kuznets curve (EKC), a country’s national income and the deterioration of its environmental quality will show an inverted U-shaped relationship. This mainly refers to the deterioration of environmental quality in the early stage of economic development as the national income increases, and the environmental quality gradually deteriorates.
However, when the economic development reaches a turning point and the industrial structure is gradually transformed into a technology-intensive industry, the environmental quality can be improved. This paper will discuss how the government sets a reasonable carbon tax. The carbon tax can accelerate industry to promote industrial investment in innovative clean energy technology and equipment for energy saving and carbon reduction in order to control the continued deterioration of environmental quality, and then improve environmental quality.

This paper studies carbon emissions from an industrial perspective, and discusses the high degree of between carbon emissions and economic growth. Guo et al. pointed out that some main industries not only consume a lot of fossil energy but also release a lot of carbon emissions. It also affects energy consumption and carbon emissions in other industries. Therefore, the government should attach great importance to these industries [2]. Zhang and Zhang studied the environmental Kuznets curve (EKC) assumption is valid for China, and the curve between carbon emissions and economic growth is in an inverted U shape [3]. Song et al. recommend that reducing carbon emissions through present technology is more difficult than reducing other pollutants. Improving energy efficiency and developing clean energy are two economically viable options in the future. However, without low-carbon technology, pursuing green growth can have a negative impact on production activities [4]. How to accelerate industrial investment in innovative clean energy technology and equipment have become important research topics. Generally, the traditional methods used to evaluate the feasibility of research and development of innovative production technology investment projects include: profitability index (PI), internal rate of return (IRR), and payback period (PP), accounting rate of return (AAR) and net present value methods (NPV). But these methods are more suitable for static investment environment. In a complex and uncertain investment environment, managers’ investment strategies should adopt a dynamic decision analysis model. Among them, the real options approach (ROA) is more able to deal with the complicated investment environment than traditional evaluation methods (Myers [5]; Dixit and Pindyck [6]). Saługa et al. proposed that real option valuation is a good assessment of the value of this flexibility. It is proposed that for coal gasification technology, real option valuation is more suitable than traditional discounted cash flow technology [7]. Balibrea-Iniesta had developed real options approach to evaluate photovoltaic energy projects with a capacity greater than 100 kW in France [8]. Deeney et al. proposed a practical-related decision support tool based on real options to help the actual evaluation of technology R&D investment, and demonstrated the decision support tool. And use it to evaluate the R&D investment potential of CO2 recycling technology for the production of energy commodities [9]. Ko et al. used a dynamic evaluation method of real options approach (ROA) to construct a decision-making model. This model explored the government's policy of levying carbon tax and subsidies to reduce carbon emissions, and rewarding companies for investment in upgrading green energy equipment. This model provided a reference basis for firms to invest in green energy equipment and government policies to control carbon emissions [10].

The important task of controlling pollution emissions is the innovation of low-carbon technology (Balsalobre-Lorente et al. [11]). And it is necessary to formulate regulations and policies for the environment of energy consumption and carbon emissions (Chen et al. [12]). From the financial point of view, this paper intends to use the real options approach (ROA) combined with the environmental Kuznets curve (EKC) model to evaluate the threshold for the government to impose carbon tax. This is also the upper limit for the government to impose carbon tax on the industry. This threshold carbon tax promotes the feasibility of industrial investment in innovative clean energy technology and equipment and carbon reduction. This threshold provides the government's most appropriate reference basis for levying carbon tax. While achieving economic development, environmental quality can also be improved.

2. Decision model
This paper combines the real options approach (ROA) and the environmental Kuznets curve (EKC) to construct an economic model for the government to levy carbon tax. Suppose that a country’s economic growth and environmental quality degradation will show an inverted U-shaped relationship (EKC).
2.1. The assumption
The paper aims to control the carbon emissions of each industry in the world within a reasonable range. Due to industrial demand shocks, or due to individual firm product demand shocks, unpredictable changes occur in the output of different firms. Therefore, the government imposes different carbon taxes on changes in carbon emissions during the production process of firms. The carbon tax changes follow a random process, and the changes constitute firm-specific shocks. In addition, carbon emissions are also impacted by another overall random process. Specifically, we assume that the government's changes in the carbon tax \( P_t \) imposed on each firm-specific in the market are as follows:

\[
P_t = S \times W(t) \times Y(Q_i)
\]  

(1)

In the Eq. (1), the \( S \) is firm-specific shocks. Assuming in a competitive market, \( W(t) \) is the industry-wide shock. \( Q_i \) is the carbon emissions in the industrial production process. Among them, carbon emissions \( Q_i = Y(Q_i) \) is a function of \( Q_i \) in the industrial production process. Therefore \( Q = Y(Q_i) \) is a concave function of \( Q_i \). That is, if the output value increases at the beginning, carbon emissions will also increase. However, as the output value increases and the economy reaches a certain turning point, the industrial structure must be gradually transformed. The industry must develop innovative technologies for energy saving, carbon emission reduction and purchase new equipment. In this way, even if firms increase production capacity, they can also reduce carbon emissions. At the same time, in order to accelerate industrial transformation, the government has controlled carbon emissions within a reasonable range. The carbon emission tax levied by the government must be sufficient to induce firms to invest in energy-saving, carbon emission-reducing innovative technologies and purchase new equipment to reduce carbon emissions.

Now consider industry-wide uncertainty. If the carbon tax imposed by the government to control carbon emissions does not affect the target profit of the firm, the new firms will enter the market, and carbon emissions will increase accordingly. If the government levies a higher carbon tax, the firm must choose to invest in innovative clean energy technology and equipment, or withdraw from the market. If the firms continue to produce, it must choose to invest in sunk costs and reduce carbon emissions. Where industry-wide shock \( W(t) \) and the government levies carbon tax \( P_t \) will follow the geometric Brownian motion process:

\[
dW(t) = \alpha W(t) dt + \sigma W(t) dZ(t); \quad dP_t = \alpha P_t dt + P_t W(t) dZ(t)
\]  

(2)

Where Eq. (2), \( \alpha \) is the expected growth rate of \( W(t) \) and \( P_t \). \( \sigma \) is the standard deviation of \( W(t) \) and \( P_t \). \( dZ(t) \) is the increments of the standard Wiener process. Here, \( E[dZ(t)] = 0 \), \( E[dZ(t)^2] = dt \). In addition to considering the carbon emissions generated by changes in output, firms have an impact on the government's carbon tax. At the same time, firms need to respond to the increase in the amount of carbon emissions in the environment when new firms entering the market are uncertain in the competitive market. In this way, the government will impose a higher carbon tax, and firms will also increase production costs. In order to sustainably operate, increase target profits and corporate social responsibility, firms should choose to invest in innovative clean energy technology and equipment. Therefore, when the carbon emissions \( Q = Y(Q_i) \) changes with \( Q_i \), the government levies carbon tax \( P_t \) and industry-wide uncertainty \( W(t) \) to form an equal rate change.

2.2. Decision model
The government levies carbon tax for firms, which affects the investment in innovative clean energy technology and equipment. The path of levying carbon tax depends on the carbon emissions \( Q = Y(Q_i) \). Therefore, the cost of corporate carbon emissions \( C(P_t, Y(Q_i)) \) is a function of carbon emissions \( Q = Y(Q_i) \) and carbon tax \( P_t \). This study denotes by \( C(P_t, Y(Q_i)) \), the expected future emission cost discount value is shown as Eq. (4):
\[
E \left[ \int_0^\infty C(P(t), Y(t)) e^{-rt} dt \right] = \frac{P(t) \times Y(Q_i)}{r - \alpha}
\]

Where, \(r\) is the risk-free discount rate. It is expected that the carbon tax that firms will pay in the future is the discount value of carbon emission \(Q_i = Y(Q_i)\) multiplied by the government's carbon tax per ton of carbon emissions \(P(t)\).

Assuming that firms invest in innovative clean energy technology and equipment, they need to invest in sunk cost \(I\). When the government's carbon tax \(P(t)\) is raised to the upper limit, firms will face the sunk cost of choosing to invest. Otherwise, firms will withdraw from the market due to the excessively high production costs caused by the government's carbon tax. When the government levies the present value of the carbon tax is greater than or equal to the depreciation expense of the sunk cost \(P(t) \times Y(Q_i) / (r - \alpha) \geq g \times I\). Then the firm will consider the sunk cost of investment \(I\). In this way, the firms can reduce carbon emissions and at the same time reduce the cost of carbon emissions during production. Wherever \(g\) is the depreciation rate of the new equipment. If \(P(t) \times Y(Q_i) / (r - \alpha) < g \times I\), the firms will not change the production model. At the same time, the industry continues to have new firms entering the market. Because the carbon tax levied by the government is not enough to threaten the target profits of enterprises, it can't induce firms to invest in clean energy to renew production equipment motivation.

Under the assumption that changes in the government's carbon tax follow the geometric Brownian motion process. The government levies different carbon taxes in accordance with the uncertain changes in industrial carbon emissions. Then the government's levy of carbon tax affects firms' investment in innovative clean energy technology and equipment. The management flexibility value is as follows Eq. (4):

\[
V [C(P(t), Y(Q_i)) = \rho_P(t) [C(P(t), Y(Q_i)) \partial_P(t) + \frac{1}{2} \rho_P(t) \partial_P(t)[C(P(t), Y(Q_i))] \partial_P(t)^2
\]

Whereby \(\rho_P(t)[C(P(t), Y(Q_i))\) and \(\rho_P(t)[C(P(t), Y(Q_i))\) are the first and the second-order differential equations derived from \(V[C(P(t), Y(Q_i))\) for \(P(t)\). Using the value matching condition (VCM): At the optimal threshold \(P(t)^* = \bar{P}_t(t)\), the management flexibility strategy value \(V[C(P(t), Y(Q_i))] = \beta_P(t)^*\) is equal to the current value of the expected government's carbon tax (the production cost of carbon emissions in the production process of the firms) \(E \left[ \int_0^\infty C(P(t), Y(Q_i)) e^{-rt} dt \right] \) minus the depreciation expense \(g \times I\). This value matching condition (VCM) satisfies the value-uniqueness condition, such as in Eq. (5). Then, the marginal value is equal in the first-order derivative function, that is, it satisfies the conditions of equal marginal value. This is a smooth-pasting condition (SPC), such as in Eq. (6) (Dixit and Pindyck [6]):

\[
\frac{\partial V [C(P(t), Y(Q_i))]}{\partial P(t)} = E \left[ \int_0^\infty C(P(t), Y(Q_i)) e^{-rt} dt \right] - g \times I
\]

\[
P(t)^* = \bar{P}_t(t)
\]

is the optimal threshold of carbon tax imposed by the government in the production process of firms, and its management flexibility value \(V[C(P(t), Y(Q_i))]\) is showed as in Eq. (7):

\[
V[C(P(t), Y(Q_i))] = \left[ \beta_P(t)^*, P(t) < P(t)^* \right] - g \times I, P(t) < P(t)^* \]

When \(P(t) < P(t)^* = \bar{P}_t(t)\), the carbon tax imposed by the government is less than the optimal carbon tax. Therefore, the government's levy of carbon tax will increase the production cost of the firm, which will not affect the target profit of the firm. Hence, there are still new firms entering the market in this.
industry. Carbon emissions will continue to increase. At this time, the government will adopt a strategy of continuously increasing the carbon tax to curb the industry's carbon emissions. Until \( P_t \geq P_{t-1} \), when the government's carbon tax is greater than or equal to the optimal threshold, the firm will choose to invest in innovative clean energy technology and equipment, and invest in sunk cost \( I \). Or they cannot reach the target profits of the firm and withdraw from the market because they need to pay a too high carbon tax. From Eq. (15), use value matching condition (VMC) and smooth-pasting condition (SPC) to solve the optimal threshold, as in Eq. (8) (Dixit and Pindyck [6]):

\[
A_P(t) = \frac{P_t \times Y(Q_t)}{r-a} - g \times I
\]

(8)

Reorganize Eq. (8), firms invest in innovative clean energy technology and equipment, invest in sunk costs, and reduce carbon emissions. The optimal threshold \( P_t \geq P_{t-1} \) for the government to levy carbon tax, such as Eq. (9):

\[
P_t = P_{t-1} = \frac{\beta_h}{A-1} \times \frac{g \times I \times (r-a)}{Y(Q_t)}
\]

(9)

In Eq. (9), \( Y(Q_t) \) is a function of carbon emissions in the production process of the firms \( Y(Q_t) = Q_t \), and its change is affected by the output \( Q_t \). Therefore \( Y(Q_t) \) is a concave function of \( Q_t \). This paper assumes that it is an environmental Kuznets curve (EKC), and the output and carbon emissions present an inverted U-shaped relationship, and its function is as Eq. (10):

\[
Y(Q_t) = a \times Q_t^b + b \times Q_t + c
\]

(10)

Then Eq. (10) is a function of carbon emissions, assuming that the output \( Q_t \) and carbon emissions \( Y(Q_t) \) present an inverted U-shaped relationship. Now, \( a < 0, \ b > 0, \ c \geq 0 \). After sorting out Eq. (9) and Eq. (10), the optimal threshold for the government to levy carbon tax, such as Eq. (11):

\[
P_t = P_{t-1} = \frac{\beta_h}{A-1} \times \frac{g \times I \times (r-a)}{Y(Q_t)}
\]

(11)

Solve the optimal threshold of the government's carbon tax \( P_t \geq P_{t-1} \) from the above construction model. When the government levies carbon tax \( P_t \geq P_{t-1} \), firms will choose to invest in sunk costs to innovate clean energy technology and update production equipment. When the government formulates carbon tax to reach the optimal threshold \( P_t \geq P_{t-1} \), firms must choose to invest in sunk cost innovative clean energy technology and equipment. Firms can reduce carbon emissions, reduce carbon tax costs, and increase profits. This optimal threshold \( P_t \geq P_{t-1} \) provides a reference for the government to formulate environmental protection policies, levy carbon taxes, and force firms to invest in innovative clean energy technology and equipment.

3. Numerical examples

The paper first assumes that the industrial output and carbon emissions appear an inverted U-shaped relationship, which is the hypothesis of the environmental Kuznets curve (EKC). The numerical example uses the carbon emissions of industrial products from 1990 to 2017 [14] are dependent variables \( Y\). In addition, the data of the total domestic industrial production from 1990 to 2017 [15] are independent variable \( Q \). Using Polynomial Regression to derive the output value \( Q \) and carbon emission function \( Y(Q_t) \) in the production process of the firms, the parameter value is as Eq. (12):

\[
Y(Q_t) = a \times Q_t^2 + b \times Q_t + c = -0.58 \times Q_t^2 + 1.80 \times Q_t + 4.97
\]

(12)

The parameter values are \( a = -0.58, \ b = 1.80 \) and \( c = 4.97 \). Then the maximum value is obtained by the first-order derivative function Eq. (12), and the maximum value is as Eq. (13):

\[
Y_{Q_t}(Q_t) = 2 \times (-0.58) \times Q_t + 1.80 = 0, \ Q_t = 1.55
\]

(13)
Then, the change in the growth rate of domestic industrial production from 1990 to 2017 [15] will affect the government's taxation of carbon emissions \( P_t \). Based on this data, the expected growth rate and standard deviation of the government's carbon tax \( x_t \) are evaluated. The related exogenous variable assumptions are shown in Table 1:

| Exogenous variables | Significance | Value |
|---------------------|--------------|-------|
| \( \alpha \) | \( \alpha \) is expected growth rate of \( W(t) \) and \( P_t \). | 0.02 |
| \( \sigma \) | \( \sigma \) is standard deviation of \( W(t) \) and \( P_t \). | 0.20 |
| \( r \) | Risk discount rate. | 0.15 |
| \( \Omega_t \) | Industrial output (trillion). | 1.55 |
| \( a \) | This parameter is a function of output and carbon emissions in the production process of the firm \( (Y(Q)) \). | -0.58 |
| \( b \) | This parameter is a function of output and carbon emissions in the production process of the firm \( (Y(Q)) \). | 1.80 |
| \( c \) | This parameter is a function of output and carbon emissions in the production process of the firm \( (Y(Q)) \). | 4.97 |
| \( I \) | Innovative clean energy technology and equipment to invest in fixed costs (Unit: million dollars). | 7.75 |
| \( g \) | Depreciation rate of new production equipment. | 0.20 |

Derived from the external variables and numerical data in Table 1, the numerical analysis results: The optimal threshold for the government to impose carbon tax is \( P_t = 498.54 \) (dollars). This threshold is when the government imposes carbon tax of \( 498.54 \) (dollars) per ton of carbon emissions, firms will choose to invest in innovative clean energy technology and equipment in Taiwan. If the government levies carbon tax \( P_t < 498.54 \) (dollars), the carbon tax imposed by the government will not affect the target profit of the firm, and the firm will choose to delay investment. When the government levies carbon tax to reach the optimal threshold \( P_t = 498.54 \) (dollars), the cost of the tax affects the target profit of the firms. At this time, firms will choose to invest in innovative clean energy technology and equipment to reduce carbon emissions. At the same time, the variable cost of carbon tax can be reduced. It also cooperates with the government's environmental protection policy and can fulfill corporate social responsibilities. The optimal threshold can provide a reference basis for the government to formulate a carbon tax policy and for firms to invest in innovative clean energy technology and equipment.

4. Conclusion
From a financial point of view and a flexible management strategy perspective, this paper combine the real options approach (ROA) with the Environmental Kuznets Curve (EKC) model to construct a carbon taxation strategy model for controlling carbon emissions. Discuss the environmental protection issues of how the government can effectively control carbon emissions. In the model, it is assumed that the industrial development model conforms to the Environmental Kuznets Curve (EKC) model. When the industry reaches a certain turning point, the industrial structure must be transformed to innovate clean energy technology and update production equipment to improve carbon emissions. Under the assumption of a perfectly competitive market, industry-wide shock \( W(t) \) and carbon tax \( P_t \) will follow the geometric Brownian motion process. Use the real options approach to construct the government's decision-making model for levying carbon tax and derive the optimal threshold for the government to levy carbon tax \( P_t \). The threshold is for the government to impose an optimal carbon tax on firms. If the government levies carbon tax on firms to reach this threshold, the firms will choose to invest in the
development of innovative clean energy technology and equipment to improve carbon emissions; otherwise, they will choose to withdraw from the market. The analysis results of the above numerical examples are shown, when the government imposes carbon tax of 498.54 (dollars) per ton of carbon emissions, the cost of the carbon tax will affect the firm's target profit. Firms will choose to innovate clean energy technology and update production equipment, otherwise they must exit the market.

The results of this study mainly provide the government how to pricing carbon tax without affecting the target profit of the firms and the GDP. Accelerate firms to innovate clean energy technology and update production equipment to improve carbon emissions. This method can effectively control carbon emissions and achieve a win-win strategy for economic development and environmental protection.

Acknowledgments
The authors would like to thank the Supported by The Professorial and Doctoral Scientific Research Foundation of Huizhou University, for financially supporting this research under Contract No. 2020JB072.

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