Doing Nothing? Carbon Abatement Decisions of Pure Monopoly Airlines under a Dynamic Aviation Carbon Tax

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Abstract. The aviation carbon tax is a critical policy instrument for emission reductions, yet its impact on airline operations remains under explored. This study investigates the optimal capacity and abatement investment decisions of a monopolistic airline under a dynamic aviation carbon tax. By constructing and solving three models—no tax, tax without abatement, and tax with abatement—we derive equilibrium solutions revealing key insights. When initial carbon allowances are sufficient, the tax policy becomes ineffective. When allowances are scarce, the airline's abatement level and cost become critical determinants of its optimal strategy. Interestingly, a larger market size or lower abatement cost may paradoxically reduce the airline's tolerance for the carbon tax. Moreover, under sufficiently high tax rates, even environmentally conscious green airlines may find it optimal to abandon abatement investments altogether. This research provides theoretical contributions and practical insights for airlines in countries with low carbon regulations as they navigate increasingly stringent aviation carbon tax policies.

Keywords: Carbon Abatement Technology Investment; Aviation Carbon Tax; Carbon Allowances; Monopoly Airline.

1 Introduction

Since the European Union included the aviation sector in the Emissions Trading System (EU-ETS) in 2008, carbon reduction policies have been continuously tightening. Although the 'stop decree' issued in 2013 temporarily suspended taxation on international flights, the Carbon Border Adjustment Mechanism (CBAM) passed in 2022 has explicitly stipulated that carbon tariffs will officially take effect in 2026, and free allowances will decrease year by year. This indicates that the EU is very likely to restart aviation carbon taxes in the near future. Aviation carbon taxes bring significant financial pressure to airlines in countries with low carbon regulation (such as China and India): It is estimated that Jet Airways and Kingfisher Airlines in India could face an

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annual additional cost of 30-40 million USD. [1]China's civil aviation industry alone had to pay about 800 million RMB in 2012, with a total of 17.6 billion RMB over nine years, and each additional flight to Europe increases the annual cost by 15 million RMB. In response to this pressure, technological emission reduction has become a consensus, with sustainable aviation fuel (SAF) being a key focus. However, emission reduction technologies are still in the early stages of development and are relatively costly, and whether high-carbon-emission airlines truly benefit from investment in emission reduction requires further research. Meanwhile, Chinese airlines are actively exploring measures such as auxiliary power replacement, application of new flight technologies, introduction of environmentally friendly aircraft models, and digital fuel management, but investment decisions still require scientific guidance.

Based on the above policy background and the carbon reduction measures of airlines, in the future, airlines will face a difficult situation where they need to pay 'aviation carbon taxes' while also investing in carbon reduction technologies to meet various policies. Therefore, this paper constructs three decision models of a fully monopolistic airline under the conditions of no aviation carbon tax, aviation carbon tax but no investment in carbon reduction technology, and aviation carbon tax with investment in carbon reduction technology to study the following issues:

(1) After imposing aviation carbon taxes in high-carbon-regulation countries, how should airlines from low-carbon-regulation countries, mainly developing countries, make optimal capacity allocation and emission reduction decisions in the face of continuously tightening initial carbon allowances, and is it necessary to invest in carbon reduction technologies;

(2) To explore the factors influencing airlines' emission reduction decisions at different stages of aviation carbon tax implementation;

(3) To analyze the impact of aviation carbon tax policy implementation on total carbon emissions, airline profits, and social welfare.

2 Literature Review

The European Union has extended the carbon emissions trading system to the international aviation sector, forming an aviation carbon tax. To study its impact, Qiao Han et al. (2014) and Zheng et al. (2017) analyzed the response strategies of different country groups from a national perspective using non-cooperative game theory [1,2].Valdés et al. (2021) and Hajek et al. (2021) confirmed from the industry level that although carbon taxes can reduce emissions, they have a negative impact on air travel demand [3,4]. The above studies mainly focus on the macro level and the demand side of the market, without involving the capacity investment and emission reduction decisions of airlines on the supply side.

Carbon quota allocation is the core mechanism of the aviation carbon tax. Existing research mostly discusses the impact of carbon quotas on corporate decision-making from a supply chain perspective (Xia et al., 2013; Xu et al., 2015) [5,6]. In the aviation

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field, Delft (2005) and Janina & Wolfgang (2007) analyzed the impact of different quota schemes on airline costs [7,8]; Brueckner & Zhang (2010) studied the effect of carbon trading prices on ticket prices and service quality [9]. However, these studies did not consider the feature of dynamically tightening carbon quotas over time. In terms of emission reduction decisions, Du et al. (2016, 2020) explored low-carbon production and emission reduction costs under total control and trading mechanisms [10,11]. Sheu & Li (2014), Nava et al. (2018) studied airline pricing, competition, and emission reduction strategies under the carbon trading mechanism [12-13]. However, most of these studies are based on a static total control and trading background, lacking a systematic analysis of airline decision-making under dynamic carbon quota constraints after the aviation industry was included in the EU-ETS. The most relevant to this paper is the study by Xu et al. (2018) on the setting of aviation passenger carbon taxes [14], which demonstrated the effectiveness of a quota-tax mechanism. However, this study did not deeply explore the impact of dynamic changes in carbon quotas on endogenous emission reduction decisions of airlines.

In summary, existing literature mostly approaches the topic from a macro perspective or within the supply chain field, lacking research on how airlines make capacity investment and emission reduction investment decisions under dynamically tightened aviation carbon taxes. This paper focuses on monopoly airlines, constructing decision models under different carbon allowance allocation scenarios, solving for the optimal capacity and emission reduction rate, and analyzing the impact of factors such as market size and carbon tax rates, providing theoretical references for airlines.

3 Problem Description and Model Construction

Consider an airline from a country with low carbon emissions and a complete monopoly on an international route connecting to a country with high carbon emissions. Airlines invest capacity $q_i(i = N, R, T)$ with unit cost c, and face the linear inverse demand function $p_i(q_i) = a - q_i$, where $a(0 < a \le \bar{a})$ is the market size. Airlines generate e_i per unit of carbon emissions in their operations. If a carbon tax is implemented, the government will initially allocate an initial carbon allowance $\bar{E}$. If the quota is sufficient, the remaining quota will bring α unit income; If there is a shortfall of quota ($0 \le \bar{E} < e_N q_N^*$), the excess is taxed at the rate t. Airlines can choose to invest in emission reduction technologies (cost$C_T = \frac{\gamma}{2}\tau^2$, τ is the emission reduction rate) to reduce emissions per unit to $e_i = e_T q_T$. Social welfare $SW_i = \pi_i + CS_i - SC_i$, of which consumer surplus $CS_i = \int_0^{q_i}[p_i(x) - p_i(q_i)]dx = \frac{q_i^2}{2}$, social cost $SC_i = \theta e_i q_i$, where $\theta > 0$.

This paper constructs three models: Model N (benchmark): no aviation carbon tax, Model R: carbon tax but airlines do not invest in emission reduction technologies, and Model T: carbon tax and airlines invest in emission reduction technologies.

4 Model solving and analysis

4.1 Baseline Model N: No Aviation Carbon Tax

The airline maximizes profit $Max\pi_N(q_N) = (p_N - c)q_N$, obtaining the optimal solution $q_N^* = \frac{a-c}{2}$, the optimal ticket price $p_N^* = \frac{a+c}{2}$, total carbon emissions $E_N^* = \frac{(a-c)e_N}{2}$, profit $\pi_N^* = \frac{(a-c)^2}{4}$, and social welfare $SW_N^* = \frac{(a-c)[3(a-c)-4\theta e_N]}{8}$.

4.2 Model R: Carbon tax, no emission reduction investment

When the initial carbon quota is insufficient$(0 \le \bar{E} < e_N q_N^*)$, the airline's decision depends on the relationship between its emissions and the quota.

Theorem 1: The optimal capacity input of model R is a piece wise function:

$$q_R^* = \begin{cases} \frac{a-c-e_N t}{2}, 0 \le \bar{E} < e_R q_R \\ \frac{a-c-\alpha e_N}{2}, e_R q_R \le \bar{E} < e_N q_N^* \end{cases} \tag{1}$$

Proposition 1 (Impact of Market and Environmental Policies): When there is a quota shortage and a tax is required $(0 \le \bar{E} < e_N q_N^*)$, $\frac{\partial q_R^*}{\partial a} > 0$, $\frac{\partial p_R^*}{\partial a} > 0$. That is, as the carbon tax increases, airlines reduce capacity and raise ticket prices. At this time, total carbon emissions E_R, profit π_R^*, and social welfare SW_R^* all decrease with the increase of the carbon tax rate t. This indicates that without investing in emission reduction, although the carbon tax can effectively reduce emissions, it also harms corporate profits and social welfare.

4.3 Model T: There is a carbon tax, and investment in emission reduction

Airlines simultaneously decide on capacity q_T and emission reduction rate τ^* to maximize profits.

Theorem 2: The optimal capacity and emission reduction rate of model T are:

$$q_T^* = \begin{cases} \frac{\gamma(a-c-e_N t)}{2\gamma - e_N^2 t^2}, 0 \le \bar{E} < e_T q_T \\ \frac{\gamma(a-c-\alpha e_N)}{2\gamma - \alpha^2 e_N^2}, e_T q_T \le \bar{E} < e_N q_N^* \end{cases} \tag{2}$$

$$\tau^* = \begin{cases} \frac{e_N t(a-c-e_N t)}{2\gamma - e_N^2 t^2}, 0 \le \bar{E} < e_T q_T \\ \frac{e_N t(a-c-\alpha e_N)}{2\gamma - \alpha^2 e_N^2}, e_T q_T \le \bar{E} < e_N q_N^* \end{cases} \tag{3}$$

The maximum carbon tax that airlines can bear is $0 < t < \frac{2\gamma}{(a-c)e_N}$.

Inference 2: When the market scale a is large or the emission reduction cost coefficient γ is small, investing in emission reduction technology may actually lower the maximum carbon tax that airlines can bear. This is because, under optimistic expectations, airlines will significantly increase capacity, causing the total cost of carbon tax expenditure and emission reduction investment to exceed the additional revenue.

Inference 3 (Threshold for Emission Reduction Decisions): Airlines' emission reduction decisions depend on the carbon tax t and the emission reduction cost C_T.

When $\gamma > \frac{(a-c)^2}{2}$ and $0 < t < \frac{a-c}{e_N}$, or $\gamma \leq \frac{(a-c)^2}{2}$ and $0 < t < \frac{2\gamma}{(a-c)e_N}$, investing in emission reduction is better.

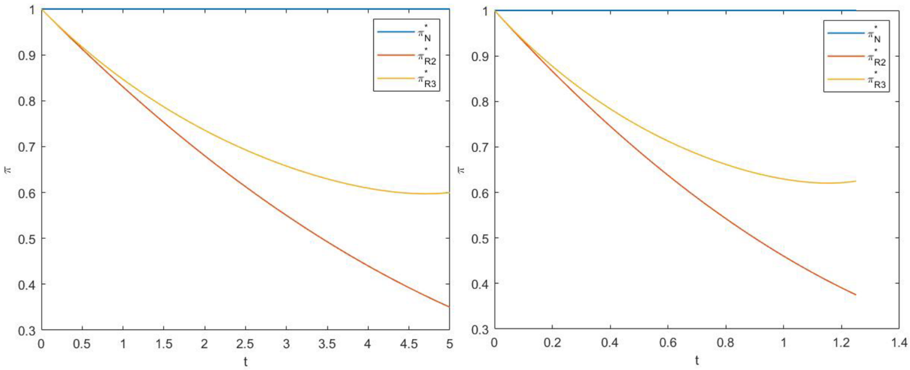
When $\gamma \leq \frac{(a-c)^2}{2}$ and $\frac{2\gamma}{(a-c)e_N} < t < \frac{a-c}{e_N}$, it is better not to invest in emission reduction.

When $t \geq \frac{a-c}{e_N}$, the airline cannot make a profit and exits the market.

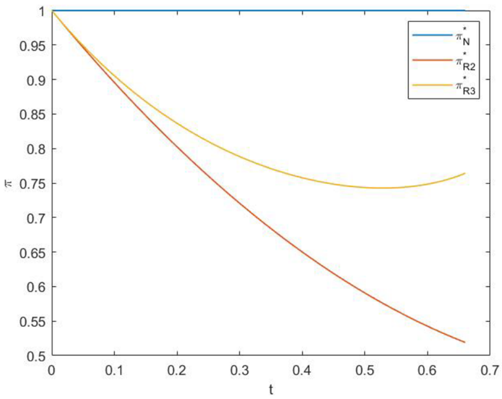
5 Numerical Analysis

In order to further explore the impact of different emission reduction decisions by airlines on total carbon emissions, profits, and social welfare when airlines face an initial shortage of carbon allowances, this chapter conducts a detailed analysis using numerical methods. The parameters set in this paper are as follows: $a = 2, c = 0, \gamma = 1, \theta = 0.75, e_N = 0.2; 0.8; 1.5$, which represent low-carbon emission airlines, medium-carbon emission airlines, and high-carbon emission airlines, respectively. As shown in Fig. 1 to 3.

As can be seen from Fig. 1, regardless of the emission level, investing in emission reduction technology (Model T) always brings higher profits than not investing (Model R). Moreover, airlines with higher initial emissions benefit more from emission reduction.

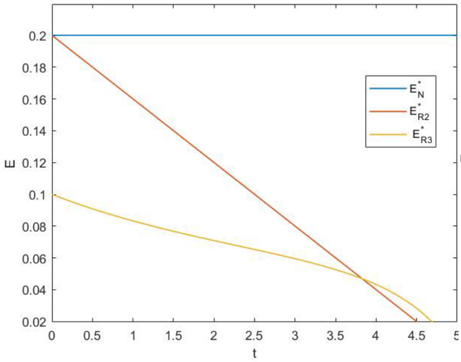


(a) $e_N = 0.2$, $\bar{E} = 0.02$ (b) $e_N = 0.8$, $\bar{E} = 0.1$

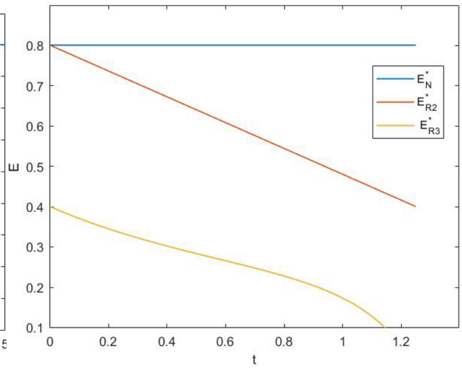


(c) $e_N = 1.5$, $\bar{E} = 0.4$

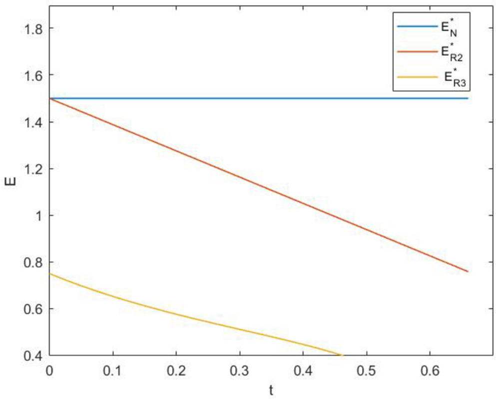
Fig. 1. Graph of the relationship between airline profits and carbon tax rates



(a) $e_N = 0.2$, $\bar{E} = 0.02$



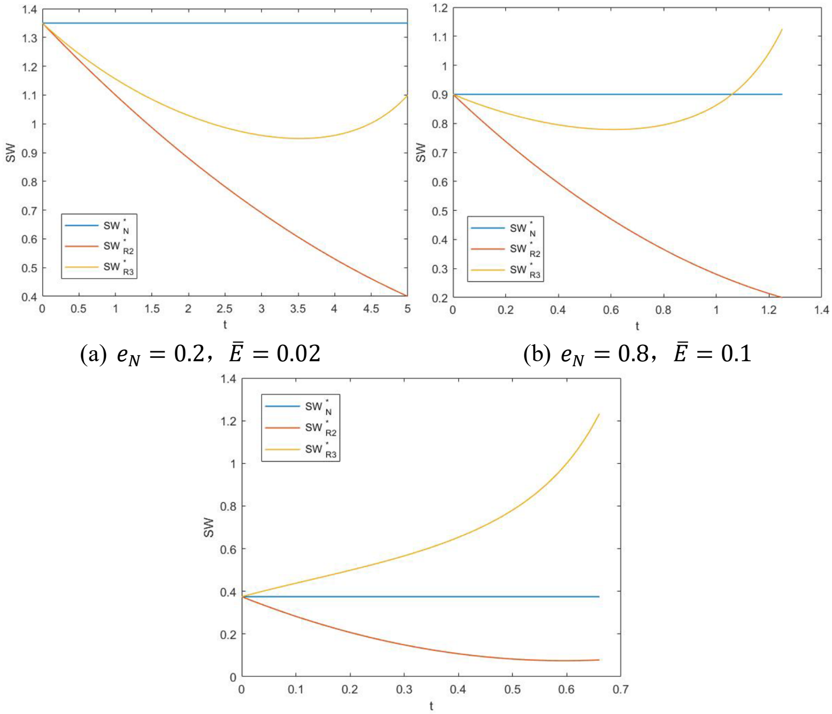
(b) $e_N = 0.8$, $\bar{E} = 0.1$



(c) $e_N = 1.5$, $\bar{E} = 0.4$

Fig. 2. Graph of the relationship between total airline carbon emissions and carbon tax rates

As can be seen from Fig. 2, investing in emission reductions usually more effectively lowers carbon emissions. However, for low-carbon emission airlines, when the carbon tax rate is relatively high, investing in emission reductions can stimulate excessive capacity growth, causing total emissions to surpass the scenario without investment. In this case, 'governing by doing nothing' is actually more environmentally friendly.



(a) $e_N = 0.2$，$\bar{E} = 0.02$ (b) $e_N = 0.8$，$\bar{E} = 0.1$

(c) $e_N = 1.5$，$\bar{E} = 0.4$

Fig. 3. Relationship Chart Between Airline Social Welfare and Carbon Tax Rate

As can be seen from Fig. 3, the impact of investment in emission reduction on social welfare varies depending on the airline. For high-emission airlines, investment in emission reduction can lead to a significant improvement in social welfare; whereas for low-carbon airlines, especially under high tax rates, investment in emission reduction can increase social costs due to capacity expansion, thereby reducing social welfare.

6 Conclusion

This paper studies the impact of dynamic aviation carbon taxes on capacity investment and emission reduction strategies by constructing decision models for a monopolistic airline under three scenarios: without a carbon tax, with a carbon tax but no emission reduction, and with a carbon tax and emission reduction, and draws the following conclusions and management implications.

First, an airline's response strategy should match its carbon reduction capability. For traditional airlines that have not invested in carbon reduction technologies, they need to closely monitor changes in the carbon tax. When tax rates are high, they should proactively reduce capacity to control carbon tax expenditures while appropriately raising ticket prices to maintain revenue. As for green airlines that have invested in carbon reduction technologies, if their reduction level is high, they can leverage their low-carbon advantage to expand capacity and capture market share; if the reduction level is low, they still need to prudently control capacity to avoid increasing the burden due to excessive carbon reduction costs.

Secondly, the study found a phenomenon worth noting: when the market size is relatively large or the cost of investing in emission reduction technologies is low, airlines tend to become overly optimistic, investing heavily in emission reduction technologies while simultaneously significantly increasing capacity. As a result, the growth in carbon tax expenses and R&D costs exceeds the benefits, thereby reducing their ability to bear the carbon tax. At this point, the government can guide companies to invest rationally through technology subsidies, helping them maintain stability in international competition.

Third, the pressure of the carbon tax has a significant coercive effect on enterprises. Most traditional airlines still need to invest moderately in emission reductions to avoid high tax burdens, but when the carbon tax rate is too high and exceeds the company's tolerance, even environmentally willing green airlines have to temporarily abandon emission reduction investments and adopt a "laissez-faire" strategy to prioritize survival.

Fourth, from the perspective of different objectives, the effectiveness of emission reduction strategies varies. When the goal is profit maximization, investing in emission reduction is generally beneficial, especially for high-emission airlines where the gains are most apparent; from an environmental benefits perspective, emission reduction investments usually lower carbon emissions, but low-emission airlines may actually see total emissions increase under high tax rates due to capacity expansion, making non-investment more environmentally friendly in this case; from the perspective of social welfare, the positive effects of emission reduction investments are most prominent for high-emission airlines.

Finally, in the face of continuously tightening carbon tax policies in regions such as the European Union, governments of countries with low carbon emission regulations cannot remain idle. Without timely intervention, domestic airlines will face huge tax burdens or even be forced to withdraw from international routes. The government should help high-emission airlines overcome difficulties through financial subsidies to prevent capital outflow, while also guiding green technology research and development through special incentives, improving the entire industry's emission reduction capacity and international competitiveness.

Future research can be expanded in the following directions: considering carbon trading mechanisms between airlines or across industries; analyzing game behavior in oligopolistic markets; exploring complex situations of capacity and demand mismatches; and incorporating government countermeasures such as subsidies or national carbon trading systems, to make the research more aligned with the real policy environment.

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