Optimal Pricing and Reputation Investment for Sustainable Aviation Fuel with Herd Effects and Heterogeneous Customers

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1 INTRODUCTION

As public awareness of carbon emission reduction increases, the corporate social responsibility (CSR) of mobility service providers regarding energy conservation and emissions has garnered significant consumer attention and will influence their choices. This study investigates the growing significance of CSR reputation for mobility service providers, particularly airlines investing in sustainable aviation fuel (SAF). A two-stage sequential decision model is employed to determine the optimal reputation investment strategies, considering the impact of herd effects, congestion effects, and customer heterogeneity. The model analyzes two pricing strategies: uniform pricing with uniform service and differentiated pricing with distinct services for different customer groups (e.g., Lufthansa offers both traditional fare and green fare, which reduce carbon emissions through the use of SAF and climate protection projects). By introducing an integrated efficiency indicator (η), this study evaluates optimal reputation investment levels, pricing strategies, and overall profitability. Findings suggest that herd effects enhance reputation investment, and a break-even point of η exists between the implementation of uniform and differentiated pricing.

2 Model Formulation

2.1 Problem Statement

We consider an airline that invests in and operates an air transport route to provide air mobility services for two distinct customer groups: Price-only sensitive group (G_p) and general group (G_g). As shown in Fig. 1, the airline initiates the reputation investment process to attain the desired reputation level r. Subsequently, based on the achieved r, the airline selects the pricing strategy, opting for either the uniform or differentiated pricing to align with the market conditions and establish the corresponding service prices: uniform price p_0 and differentiated prices p_1, p_2. Upon receiving the service price and reputation level, customers in the price-only sensitive group

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(G_p) promptly decide on their purchase. Conversely, customers in the general group (G_g), who are influenced by the **herd effect**, may exhibit varied behaviors: some customers with higher willingness-to-pay (WTP) make immediate purchases in Period 1, while those with lower WTP may delay their purchase until experiencing the herd effect in Period 2.

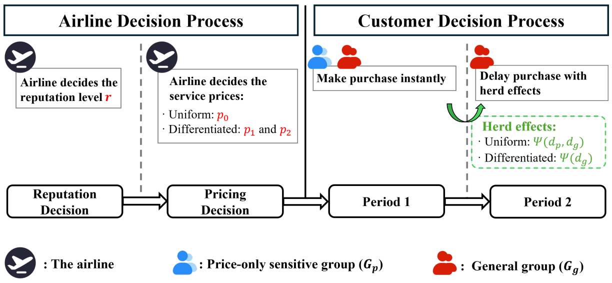


Figure 1 – *The airline decision and customer choice process for the newly launched green flight*

2.2 Strategic customers' purchase behavior

In this subsection, we present the modeling details of customers' strategic purchase decisions. At the outset, we illustrate the modeling framework for i) the attributes of customers, ii) congestion effects, and iii) herd effects, which are specified as follows:

Attributes of the two customer groups G_p and G_g. The WTP of customer, denoted as a for both G_p and G_g are uniformly distributed in $[0, A]$. The total demand of G_p and G_g is D and the ratio of the number of customers in group G_g to the number of customers in group G_p is denoted as λ. Consequently, the probability density function for G_p is $\frac{1}{1+\lambda} * \frac{D}{A}$, and for G_g, it is $\frac{\lambda}{1+\lambda} * \frac{D}{A}$.

Formulation of the congestion effect (negative externality). The congestion effect, denoted as Φ, is influenced by the realized demand of the airline throughout the selling season. To facilitate the analysis, we follow the settings in Inci & Lindsey (2015), assuming that the congestion effect is linearly increasing in the realized demand of the airline and the sensitivity coefficient for the congestion effect is denoted as γ. It is important to note that if the airline chooses uniform pricing, the congestion effect of G_g will be dependent on the demand of both groups, formulated as $\Phi(d_p, d_g) = \gamma * (d_p + d_g)$ in Period 1 and $\Phi(d_p, d_g, \hat{d}_g) = \gamma * (d_p + d_g + \hat{d}_g)$ in Period 2. However, if the airline chooses differentiated pricing, two distinct services will be offered by the airline. For those who choose the traditional fare, they need to compete with customers in G_p for seat, while for those who choose the green fare, they can enjoy the benefit of priority seat selection, resulting in the congestion effect of G_g being solely dependent on its demand, which can be formulated as $\Phi(d_g) = \gamma * d_g$ in Period 1 and $\Phi(d_g, \hat{d}_g) = \gamma * (d_g + \hat{d}_g)$ in Period 2.

Formulation of the herd effect (positive externality). The herd effect, denoted as Ψ, only manifests in Period 2, following the announcement of information by the airline and customers (Zhang *et al.*, 2020). To facilitate the analysis, we follow the settings in the two preceding studies, assuming that the herd effect is linearly increasing in the number of customers, and the sensitivity coefficient for the herd effect is β. It is important to note that if the airline chooses uniform pricing, only a single green fare (s_0) will be provided. Therefore, the herd effect will be dependent on the regular customers of both groups, which can be formulated as $\Psi(d_p, d_g) = \beta * (d_p + d_g)$. However, if the airline opts for differentiated pricing, it will offer two distinct services: traditional fare (s_1) and green fare (s_2). Customers selecting the traditional fare will not experience the herd effect, whereas those opting for the green fare will experience a herd effect dependent solely on their own customers, represented by the equation $\Psi(d_g) = \beta * d_g$.

2.3 Airline's reputation investment and pricing strategies

In this subsection, we will propose the model for the airline's reputation investment and pricing decisions. The decision process of the airline is as follows: First, the airline makes the reputation investment decision (r) such as purchase of SAFs, advertisement and improvement of the eco-friendly airplanes based on a budget M. Second, the airline determines the service price based on the established reputation level r. Here, we consider two pricing strategies: 1) the uniform pricing and 2) the differentiated pricing. This leads to a sequential-move decision problem for the airline, which can be solved by the backward induction method.

Specifically, the second stage program $\mathcal{P}_2$ can be formulated as:

$$\max_{p_p, p_g} \quad \tilde{\pi}(p_p, p_g|r) = d_p(p_p - C_p) + d_g(p_g - C_g) + \hat{d}_g(p_g - C_g) - \frac{k}{2}r^2 \tag{1}$$

$$\text{s.t.} \quad p_i - C_i > 0, \quad i = p, g \tag{2}$$

where $\tilde{\pi}(p_p, p_g|r)$ represents the profit given the fixed reputation investment r. The terms $d_p(p_p - C_p)$ and $d_g(p_g - C_g)$ signify the profit generated in Period 1 of G_p and G_g, respectively, and $\hat{d}_g(p_g - C_g)$ is the profit generated from G_g in Period 2. The cost of reputation investment in clean energy aircraft and SAFs is expressed as $\frac{k}{2}r^2$, where k signifies the cost efficiency of reputation investment Parilina *et al.* (2024).

Notably, if the airline chooses the uniform pricing, then $p_p = p_g = p_0$, $C_p = C_g = C$, and $r = r_u$. Conversely, if the airline opts for differentiated pricing, then $p_p = p_1$, $p_g = p_2$; $C_p = C$, $C_g = C + \Delta$, and $r = r_d$.

Then, by solving the second stage program, we derive $p_p^*(r)$ and $p_g^*(r)$, which are the best response functions of r. Backward to the first stage, the first stage program $\mathcal{P}_1$ can be formulated as:

$$\max_{r} \quad \tilde{\pi}(r) = d_p(p_p^*(r) - C_p) + d_g(p_g^*(r) - C_g) + \hat{d}_g(p_g^*(r) - C_g) - \frac{k}{2}r^2 \tag{3}$$

$$\text{s.t.} \quad \frac{k}{2}r^2 \leq M \tag{4}$$

Under uniform pricing, all customers from G_p or G_g receive the uniform green fare service (s_0), sharing the reputation investment cost equally. Conversely, under the differentiated pricing, both traditional fare (s_1) and green fare (s_2) are available for G_p and G_g to select freely. However, if G_g customers choose the traditional service (s_1) in period 1, they neither pay for the airline's reputation investment nor contribute to the herd effect. From the airline's perspective, the objective of implementing differentiated pricing is to effectively attract customers from groups G_p and G_g with distinct services and prices. This approach aims to ensure that customers in G_p choose the traditional service s_1 and customers in G_g choose the green service s_2. Specifically, if the following constraint under differentiated pricing is satisfied in $\mathcal{P}_1$, then perfect segmentation between the customers in G_p and G_g can be achieved: $a - p_2 - \Phi(d_g) + r_d > a - p_1 - \Phi(d_p, d_g)$. Then solving the first-stage program to yield the global optimal reputation level r^* and by replacing r with r^* in $p_p^*(r)$ and $p_g^*(r)$, the optimal prices can be obtained.

3 Model discussion

3.1 The airline's choice: Uniform or differentiated pricing?

The airline's objective is to maximize profit by selecting the most effective pricing strategy (uniform or differentiated) given the prevailing market conditions, characterized by parameters such as reputation investment cost and herd effect sensitivity. The difference in profit between the two strategies is provided below:

$$\tilde{\pi}_u^* - \tilde{\pi}_d^* = Z_1(\beta, k) * (A - U_0 - C)^2 - Z_2(\beta, k) * (A - U_0 - C - \Delta)^2 \tag{5}$$

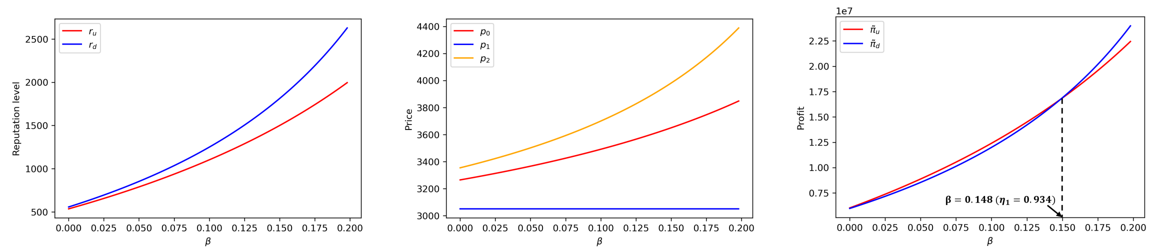
where $Z_1(\beta,k) = \frac{kh^2(l\beta+1)}{4kh-2l^2(l\beta+1)} - \frac{f}{4}$; $Z_2(\beta,k) = \frac{kl(l\beta+1)}{4k-2l(l\beta+1)}$.

$Z_1(\beta,k)$ represents the relative effectiveness of uniform pricing in capturing demand with a low unit service cost. Conversely, $Z_2(\beta,k)$ represents the relative effectiveness of differentiated pricing in attracting customers willing to pay more for green flights and additional benefits such as priority seating. The integrated efficiency indicator, η, is introduced to facilitate a comprehensive analysis of the interplay between various market factors and the optimal pricing strategy, defined as: $\eta = \frac{Z_1}{Z_2}$.

Proposition 1 *When $0 \leq \eta \leq \eta_1$, the airline is better off by choosing the differentiated pricing; while when $\eta > \eta_1$, the airline is better off by choosing the uniform pricing, where $\eta_1 = (\frac{A-U_0-C-\Delta}{A-U_0-C})^2$.*

Proposition 1 provides clear guidance on the optimal pricing strategy based on η. η_1 denotes the break-even point between the adoption of uniform pricing and differentiated pricing. This point is determined by the customer's maximum willingness to pay, the fundamental unit service cost, and the expenses associated with additional benefits. When η is high enough ($\eta > \eta_1$), uniform pricing is preferred, as the benefits of capturing the entire market with a single lower-cost service and a more effective herd effect outweigh the potential benefits of segmenting customers with differentiated services. Conversely, when η is relatively low ($\eta < \eta_1$), differentiated pricing becomes the optimal strategy. This occurs when the advantages of customizing the green service and its pricing for the G_g segment outweigh the benefits of spreading the costs of reputation investment and leveraging the herd effect across both customer groups.

We conducted a numerical experiment ($A = 4000$, $D = 40000$, $C = 2300$, $\Delta = 50$, $U_0 = 200$, $\lambda = 4$, $\gamma = 0.025$, $\beta \in [0, 0.2]$, $k = 12$, $M = 45 million$) to validate the theoretical results presented above, as detailed below:



(a) The optimal reputation level changes with β

(b) The uniform and differentiated prices change with β

(c) The uniform and differentiated profits change with η

Figure 2 – *Changes of airline's investment and pricing strategies with β and η*

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