Journal of Air Transport Management 26 (2013) 25–30

Contents lists available at SciVerse ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

Surcharge management of kerosene and CO_2 costs for airlines under the EU's emission trading

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Keywords:
Surcharge
Price risks
Emission trading
Revenue management

A B S T R A C T

We develop a fuel surcharge model for air transport in relation to kerosene and CO_2. Price increases, however, induce demand reactions, which in turn may affect profitability. We incorporate demand reactions in our model to calculate an optimal kerosene and CO_2 surcharge. We use a numerical example for an illustrative airline network and show that prices on inelastic long-haul routes are faced with the highest price increases, whereas elastic short-haul routes see relatively mild price increases. We compare our results with a traditional surcharge management approach and find them about 5% better.

1. Introduction

To curb the increase in CO_2 emissions, the European Union (EU) included airlines in the EU's emission trading scheme (ETS) from January 2012. Aviation is thus now linked to the risks of fluctuating CO_2 prices. One way to hedge against these fluctuations is to impose surcharges that pass changes of input factor prices onto customers. This, however, introduces the risk of demand reactions. We address this problem for pricing decisions under fluctuating CO_2 and kerosene prices.

2. Model development

We examine the situation using dynamic programming, a methodology developed by Bellman et al. (1955). The idea is to break a large problem into smaller sub-problems (in our case, time periods). Specifically, we want to optimize pricing for airline routes under two changing input factors: kerosene and CO_2 prices. Instead of setting optimal prices for all periods, simultaneously, we can break this large problem into smaller sub-problems and make a decision at each period after observing kerosene and CO_2 prices. This is called a closed loop system (Bertsekas, 2007). We can separate the decision problem over time as long as the formulation is additive, which is the key difficulty in formulating the problem. These optimal decisions then become optimal for the whole problem; the principle of optimality. Specifically, the goal of our model is to calculate the percentage of price change in kerosene and CO_2 that is passed onto customers during each period.

We assume a single airline network with no direct competition. Our analysis is a multi-period model, where each period is indexed with $t = 1,..,T$ and each route with $r = 1,..,R$.

We adopt a simplified airline profit equation that includes revenues given by ticket prices p_r (in € per ticket), quantities of tickets sold (given by a linear demand function $a_r - b_r{}^* p_{tr}$), and costs determined by kerosene c^K, CO_2 costs c^C and kerosene quantities calculated with a distant dependent kerosene consumption factor $k_r(d_r)$. Equations (1)–(5) show the profit formulation. The core of the profit function is Equation (1); we break each component into separate equations to facilitate understanding.

We explain each component of the profit equation, starting with the costs per tonne for kerosene and CO_2 and the kerosene consumption factor for the kerosene quantities (and the CO_2 quantities with an emission factor). Lastly, we explain ticket prices and passenger quantities.

Costs for kerosene c_t^K and CO_2 c_t^C: Input factors considered are kerosene c^K (indexed with K) and CO_2 allowances c^C (indexed with C). Prices for kerosene c_t^K (in € per tonne kerosene) and CO_2 emission rights c_t^C (in € per tonne CO_2) result from the prices of the previous period and change in prices (in percent) or, mathematically, $c_t^K = c_{t-1}^K(1 + \Delta_{t-1}^K)$. Therefore, the price of kerosene c_t^K is a result of the price of the former period c_{t-1}^K and a random realization Δ_{t-1}^K (with Δ_{t-1}^K being non-stationary and *independent and identically distributed)*, which denotes the change in value between two periods (Equation (2)). The price of CO_2 c_t^C is determined in the same way (Equation (3)).

Quantities for kerosene $k_r(d_r)$: Quantities of kerosene are determined by Equation (4). We model kerosene consumption dependent on number of passengers and distance. To calculate kerosene

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[1] We would like to thank two anonymous referees for their constructive comments.

0969-6997/$ – see front matter
http://dx.doi.org/10.1016/j.jairtraman.2012.08.013

consumption, we multiply $k_r(d_r)$ by the passenger quantity given by the demand function. The kerosene consumption calculation consists of four parts: consumption for the takeoff phase, consumption for the cruise phase, consumption penalty for long flights, and a component for the share of business class intensity.

Kerosene consumption is calculated following CompenCO2 (2011), a company that offers CO_2-offsets. Consumption during takeoff and climb out is given by consumption factor k^{TO} (in tonnes kerosene per passenger per kilometer traveled during takeoff) and the respective distance traveled in kilometer during that phase d^{TO}. We assume no flights are shorter than this phase (250 km in the numerical example). During cruise flight (the remainder of the flight $d_r - d^{TO}$) we apply a different consumption factor of k^F (in tonnes kerosene per passenger kilometer).

For the additional kerosene consumption of long-haul flights, we add a long-haul penalty, which is calculated by dividing the kilometer distance d_r by the long-haul factor d^{lh} and multiplying this figure by an additional consumption factor of k^{lh}. This means that the kerosene consumption (as determined by cruise and takeoff portions) increases by the factor d_r/d^{lh} multiplied by the long-haul factor k^{lh}. For example, if k^{lh} is set to 3% and $d_r = 8000$ and $d^{lh} = 1000$, then the kerosene consumption increases by 24% (8000 km/1000 km*3%). Cross-checking with kerosene consumption values found in Lufthansa Group (2010b) for short, medium, and long-haul routes confirms the validity of our method.

In addition to distance, kerosene consumption, per passenger, is dependent on the relation of economy seats versus premium seats (first and business class seats) as we base our calculations on economy seats. We assume a share of business class seats on a plane BC_r and a share of economy seats $1 - BC_r$. Business class seats are multiplied by an emission factor e^C. We assume twice the emission of a premium seat over an economy seat in the numerical example. We contract these parameters to a route specific emission factor of e_r^{BC} with $e_r^{BC} = (1 - BC_r)(BC_r{*}e^C)$.

Quantities for CO_2: We multiply the amount of kerosene by a fixed emission factor e with a value of 3.15 (in tonnes CO_2/tonne kerosene).

Ticket prices p_{tr}: The airline can adjust prices with a surcharge that it levies on passengers to counter changes in input factor prices. The airline would need to determine, in terms of u_{tr}, the percentage of change in prices of kerosene and CO_2 (also percentage changes) it wants to pass on to customers. To reflect the differences in both quantity and price for the input factors, we weigh price changes with prices and quantities (a multiplication with the emission factor $e = 3.15$ for CO_2). For example, for a kerosene price c^K of €700 per tonne (and a price change Δ^K of 5%) and a CO_2 price c^C of €8 per tonne (and a price change Δ^C of 10%), the weighted price change is only 5.17%.

Passenger quantities: We model demand for airline service with a linear demand function $D_{tr} = a_r - b_r{*}p_{tr}$. Airlines understand the markets they serve (and, therefore, the demand function) because of the revenue management techniques that are applied.

The profit function for one period can, using these definitions, be denoted by Equations (1)–(5):

$$\pi_t = \sum_{r=1}^{R}\left[p_{tr}(u_{tr}) - k_r(d_r)\left(c_t^K\left(\Delta_t^K\right) + ec_t^C\left(\Delta_t^C\right)\right)\right] \times (a_r - b_r \times p_{tr}) + \frac{1}{1+r}E[\pi_t + 1] \quad (1)$$

s.t.

$$c_t^K = c_{t-1}^K\left(1 + \Delta_{t-1}^K\right) \quad (2)$$

$$c_t^C = c_{t-1}^C\left(1 + \Delta_{t-1}^C\right) \quad (3)$$

$$k_r(d_r) = \left(k^{TO} \times d^{TO} + k^F \times \left(d_r - d^{TO}\right)\right)\left(1 + k^{lh}\frac{d_r}{d^{lh}}\right)e_r^{BC} \quad (4)$$

$$p_{tr} = p_{t-1,r}\left(1 + \left(\frac{c_t^K}{c_t^K + ec_t^C}\Delta_{t-1}^K + \frac{c_t^C}{c_t^K + ec_t^C}e\Delta_{t-1}^C\right)u_{t-1,r}\right) \quad (5)$$

The problem must be additive over time with all periods after the current one added to it. Because future periods include uncertainties about the prices of kerosene and CO_2, we use an expected value operator $E[\pi_{t+1}]$. For each period, a decision needs to be made that also considers the coming periods. These coming periods, in turn, depend on the decisions made during these periods. To account for time differences in these decisions, we discount the expected value with $1/1 + r$ where r is the intertemporal interest rate.

3. Solution to the formulated problem and interpretation

Solving the problem formulation for its optimal solution analytically yields a control rule. The control rule allows us to make optimal decisions given the parameters of a route. It is not necessary to recalculate the decision for all periods to determine the optimal solution. We can simply plug the parameters into the control rule and obtain the optimal decision (the level of pass-through of the price changes of kerosene and CO_2). Equation (6) shows the control rule.

$$u_{tr} = \frac{w\left(a_r d^{lh} + b_r w e_r^{BC}\left(d^{lh} + d_r k^{lh}\right)\left(d_r k^F + d^{TO}(k^{TO} - k^F) - 2b_r d^{lh} p_{tr}\right)\right)}{2b_r d^{lh}\left(c_t^K\Delta_t^K\left(1 + \Delta_t^K\right) + c_t^C\Delta_t^C\left(1 + \Delta_t^C\right)e\right)p_{tr}} \quad (6)$$

with

$$w = c_t^K\left(1 + \Delta_t^K\right) + c_t^C\left(1 + \Delta_t^C\right)e$$

Here, we provide interpretations of the control rule. Based on our assumptions (no competition and, therefore, a monopolistic price setting), we expect the results of p_{tr} to follow the markup rule (Samuelson and Marks, 2003), which states that prices in a monopoly are

$$\frac{p_{tr} - MC_{tr}}{p_{tr}} = \frac{1}{\eta_{tr}} \quad (7)$$