A FEEDBACK MODEL FOR ASSESSING OUT-OF-REGION AIRPORT LEAKAGE

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Introduction

Airport leakage is a phenomenon that occurs when air passengers choose to travel longer surface distances to take advantage of better air services at an out-of-region airport (which we term the "substitute" airport), instead of using their local airport as would be expected (Suzuki & Audino, 2003). Leakage may play a substantial role in reducing passenger volumes at the local airport, which in turn can impact regional economic development, and have significant implications for regional transportation planning and airport planning.

Previous studies of airport leakage mainly considered the impacts of the airport infrastructure and service (supply) characteristics on airport demand, and rarely consider their interaction and feedback effects. In terms of demand, discrete choice models have been used to estimate passengers' airport choice. Using basic multinomial logit, it was found that leisure travelers are more likely to leakage to out-of-region airports compared with business travelers, and that past experiences at an airport have a significant impact on passengers' airport choice (Suzuki, Crum, & Audino, 2003). A modified nested logit model was used to assess joint airport and airline choice, in the case of passenger leakage from Des Moines International Airport to Kansas City, Minneapolis-St. Paul, and Omaha Eppley International Airports (Suzuki, 2007). The airport choices of passengers originating from Rome (between two airports serving Rome and the Naples Capodichino Airport) has been analyzed using multinomial logit, hierarchical logit, cross nested logit, and mixed logit models. It was found that access time, airfare, age, experience, and income are significant factors impacting airport choice (de Luca & Di Pace, 2012). Other airport leakage studies focus on identifying an airport's geographical catchment area (Fuellhart, 2007) (Lieshout, 2012). Although the above studies demonstrate the existence of airport leakage in various contexts and identify the factors that impact an air passenger's choice to use an out-of-region airport, they do not consider how airport leakage may impact airport services at both the local and substitute airports, and how services changes may in turn impact airport choice, etc. A very limited number of studies do consider interaction effects. Suzuki and Audino (2003) explored how airfare and flight frequency of substitute airports impacted passenger volumes at 14 (local) airports in the United States (Suzuki & Audino, 2003). The study used airfare as an instrumented variable, in addition to macroeconomic variables and distances between airports, in a two-stage least squares regression model of airport passengers. The authors found that that air passenger demand at local airports may be impacted by the characteristics of substitute airports up to 250 miles away (Suzuki & Audino, 2003).

This paper attempts to address the lack of airport leakage studies that consider supply-and-demand feedback by answering two questions. Firstly, what attributes – particularly airport service attributes – affect passenger leakage to out-of-region airports? Secondly, how do airport leakage and an air service characteristic (airfare) impact one another? The objective of this paper is to investigate the interaction effects between airport leakage and different variables through a supply-and-demand feedback model. To accomplish this objective, this paper investigates the hypothesis that air passengers will forego travelling out of their local (typically medium-sized) airport in favor of taking advantages of the services offered by a major out-of-region (substitute) airport farther away.

Methods

A supply-and-demand equilibrium model is developed by combining a passenger market share model with a regression model of airfare. The market share model determines the market shares of two airports for a population that is expected to travel via a local airport, but may "leak" to a substitute airport outside the region under certain conditions. Through hypothetical numerical examples, the model demonstrates how airport attributes can affect airport market share and vice versa.

Market Share Model

Say we have passengers traveling to a certain destination airport. We assume that passengers would choose to depart from their local or substitute airport in order to maximize their own utility (or, conversely, to minimize their own generalized costs). Based on previous studies, the utility of using Airport i to travel to a given destination is shown in Equation 1 (Hess, 2004) (Hess & Polak, 2007). In Equation 1, airfare and flight frequency are simply treated as airport service attributes rather than the attributes of a given airline operating at that airport. The log-form of flight frequency indicates that the impact of a variable changes very slowly (to a point where it does not change at all) when its value exceeds a critical value, which has been verified in many studies (de Luca & Di Pace, 2012) (Harvey, 1987) (Hess, 2005) (Hess & Polak, 2007).

$$U_i = V_i + \varepsilon_i = \alpha F_i + \beta\, log(f_i) + \gamma\, log(g_i) + \varepsilon_i \qquad \textbf{(Equation 1)}$$

Where
U_i is the utility of choosing Airport i to travel to some destination airport.
V_i is the deterministic utility of choosing i.
ε_i is the stochastic utility of choosing i.
F_i is the airfare from Airport i to the destination airport.
f_i is the flight frequency from Airport i to the destination airport.
g_i is the ground access distance to Airport i.
α, β and γ are coefficients.

Let's say that Airport 1 is the medium-size local airport, and Airport 2 is the out-of-region substitute airport. The probability that Airport 1 is chosen is the probability that the utility of traveling through Airport 1 is greater than that for Airport 2. If we use a logit model for the market shares of two airports $i = 1, 2$, then:

$$MS_i = \frac{exp(V_i)}{exp(V_1) + exp(V_2)}, i = 1,2 \qquad \textbf{(Equation 2)}$$

Airfare Model

A regression model is used to represent how the local airport's passenger market share (and therefore, passenger leakage) impacts airport service attributes.

$$F_1 = f(MS_1, X_1) \qquad \textbf{(Equation 3)}$$

Where
F_1 is the average airfare from Airport 1 (local airport) to the destination airport, in dollars.
MS_1 is the market share of Airport 1.
X_1 are other variables that can influence the average airfare to a destination airport from Airport 1.

By solving Equations 2 and 3 simultaneously, we are able to consider the effects that market share and airfare at Airport 1 have on one another. The solution to these two equations is the equilibrium market share. F_2 is treated as an exogenous variable in our model.

Numerical Analysis

To perform a numerical analysis demonstrating the use of our model, we specify the exact form for Equation 3, and, in the absence of data, choose values for airport utility function coefficients.

Firstly, we specify the airfare model based on a two-stage feasible generalized least squares (FGLS) model which used U.S. flight ticket and air carrier statistics data (Fu, 2015). More specifically, the FGLS model was developed based on data for ten (local) airports in the U.S. The first stage models average airfare as a function of passenger volumes and other explanatory variables. The second stage models passenger volumes at the local airport as a function of airfare (instrument variable), total enplanement at the local airport, total enplanement at the substitute airport, and other variables (Fu, 2015). The coefficients in Equation 4 are based on travel from Jacksonville International Airport to Philadelphia International Airport, with the substitute airport being Orlando International Airport. The airfare model is shown in Equation 4.

$$F_1 = \exp(2.75 - 0.06\ln(T \cdot MS_1) - 0.07 \cdot \mathrm{I}(LCC = 1) + 0.33\ln(F_2) + 0.17\ln(FUEL * MILES)) \quad \textbf{(Equation 4)}$$

Where

T is the total air passenger demand in the metropolitan region of Airport 1.

$I(LCC = 1)$ is the low-cost carrier (LCC) indicator variable. $I = 1$ if LCCs are available at Airport 1; $I = 0$ otherwise.

F_2 is the average airfare from Airport 2 (the substitute airport) to the destination airport.

$FUEL$ is the unit fuel cost per gallon.

$MILES$ is the non-stop distance (miles) of the flight from Airport 1 to the destination airport.

The values of coefficients α and β in the utility function are based on those found or used in previous studies (Brooke, Caves, & Pitfield, 1994) (Caves, 1991) (Ndoh, 1990) (Pels E. P., 2000). They are shown in Table 1.

Finally, we use the case of Jacksonville International Airport to populate several variables. For instance, the non-stop distance between Jacksonville and Philadelphia is 742 miles. The flight frequencies at Airport 1 (f_1) and Airport 2 (f_2) are set to be 100 and 200 per quarter respectively to represent a (hypothetical) situation where Airport 2 provides better service to the destination market by offering more frequent service. The values assigned to variables are shown in Table 1.

Table 1 Assumed Values for Variables and Coefficients in Utility and Airfare Functions

Variables & coefficients	*Description*		*Value*
α	Coefficient of Airfare	Utility Function	-0.04
β	Coefficient of Frequency		1.15
γ	Coefficient of Ground Access Distance		-0.04
f_1	Flight Frequency at Airport 1 per Quarter		100
f_2	Flight Frequency at Airport 2 per Quarter		200
g_1	Ground Access Distance to Airport 1 (miles)		30
g_2	Ground Access Distance to Airport 2 (miles)		171
T	Total Passenger Demand	Airfare Function	20,000
$I(LCC = 1)$	LCC Indicator Variable, for Airport 1		0
F_2	Airfare at Airport 2 ($)		200
$FUEL$	Unit Fuel Cost ($/gallon)		3
$MILES$	Non-stop flight miles from Airport 1 to destination (miles)		742

This numerical analysis focuses on the sensitivities of equilibrium market share with respect to chosen variables and coefficients. All variables and coefficients can be assumed to take the values shown in Table 1 unless otherwise indicated.

Impacts of the Airfare Coefficient (α)

Figure 1 shows possible equilibrium values for market share using the numerical values presented in Table 1, but varying the values for the airfare coefficient α as indicated. The x-axis represents input values of market share, which we input to Equation 4 to obtain F_1 values. By inputting the F_1 values into Equation 1 and Equation 2, we will obtain a range of MS_1 values, which are called output market share as represented by the y-axis. Equilibrium only exists where each curve (corresponding to a specific α value) intersects the 45° reference line. Figure 1 shows two types of equilibria: stable and unstable. A stable equilibrium exists when the curve cuts the 45° reference line from above, when input market share increases. The market share will return to a stable equilibrium if a disturbance should happen to change the market share at any point (Hansen, 1995) (Sharov, 1996). However, if a disturbance should occur to disrupt an unstable equilibrium, the market share will not return to that equilibrium (Sharov, 1996). Unstable equilibria are unlikely to exist over the long term (Taylor & Jonker, 1978). As a result, we focus our attentions on stable equilibria.

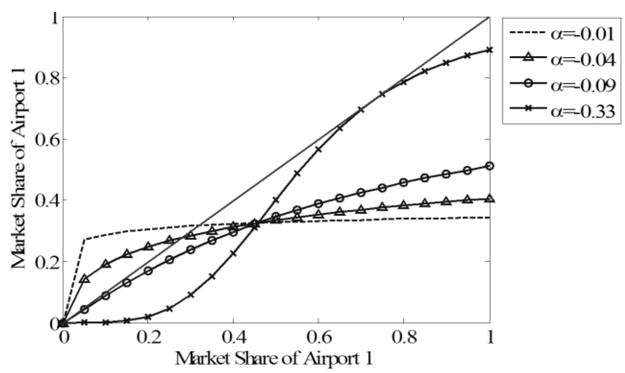

Figure 1 Equilibria under Alternative Airfare Coefficients in Utility Function

The result for $\alpha = -0.09$ and $\alpha = -0.33$ are chosen to demonstrate that the number of equilibrium solutions changes as α decreases. When α is larger than (approximately) -0.09, there are two possible equilibria. When α is slightly smaller than -0.09, there is only one equilibrium. However, if α continues to decrease to (approximately) -0.33, there will be two possible equilibria again. When α is smaller than -0.33, the number of equilibrium points increases to three, with one stable equilibrium at $MS_1 = 0$, one unstable equilibrium at $MS_1 > 0$ (which we termed a positive unstable equilibrium), and one stable equilibrium at $MS_1 > 0$ (which we termed a positive stable equilibrium). The positive stable equilibrium increases when α decreases. In addition, when $\alpha \leq -0.33$, $F_1 < F_2$ at the positive stable equilibrium (recall that F_1also varies here with MS_1). Given that α represents how much relative weight a passenger assigns to airfare when choosing an airport, relative to the other factors (explanatory variables) considered, more passengers will use the local airport when airfare is increasingly important to passengers (under the circumstances that the local airport provides lower airfare than the substitute airport). As more passengers use the local airport, airfares will also decrease due to economies of density (Lijesen, Rietveld, & Nijkamp, 2001), further magnifying the airfare advantage of the local airport. This is a positive feedback effect, meaning that an airport with higher passenger traffic will attract more passengers (Hansen, 1995), and so on. However, if airfare is less important to passengers ($-0.33 < \alpha < 0$), more passengers will use the substitute airport because it provides higher flight frequency than the local airport (i.e. $f_1 = 100, f_2 = 200$). As a consequence, airfare at the local airport increases, exacerbating to the substitute airport.

In conclusion, the airfare coefficient α impacts equilibrium values as well as number of different market share scenarios. Its effect on the value of positive stable equilibrium is related to the values of the flight frequency coefficient, ground access distance coefficient, and flight frequencies at the two airports. Generally, these results support the positive feedback effect where more passenger market share at the local airport would reduce its airfare, further attracting more market share to this airport (Hansen, 1995).

Impacts of the Substitute Airport's Airfare (F_2)

In the previous results we found that there is one stable equilibrium when F_2 changes. As a result we are interested in how F_2 impacts this equilibrium, through its impacts on MS_1 and on F_1. Here we will discuss about the combination effect of F_1 and F_2 on the stable equilibrium for market share, using the numerical values presented in Table 1 but varying the values for substitute airport airfare (F_2). As shown in Figure 2, when F_1/F_2 increases, MS_1 decreases. This means that when the substitute airport has increasingly lower airfares compared to those at the local airport, it will take more market share from the local airport. Even when F_1 is lower than F_2 ($F_1/F_2 < 1$), $MS_2 > 0$ and there is still airport leakage. This is because the flight frequency at the substitute airport is higher than the local airport (i.e. $f_1 = 100, f_2 = 200$). When $\alpha = -0.04$, $\beta = 1.15$, $f_1 = 100$, and $f_2 = 200$, $MS_1 = 0$ and no passenger leakage occurs if $F_1/F_2 < 0.6$.

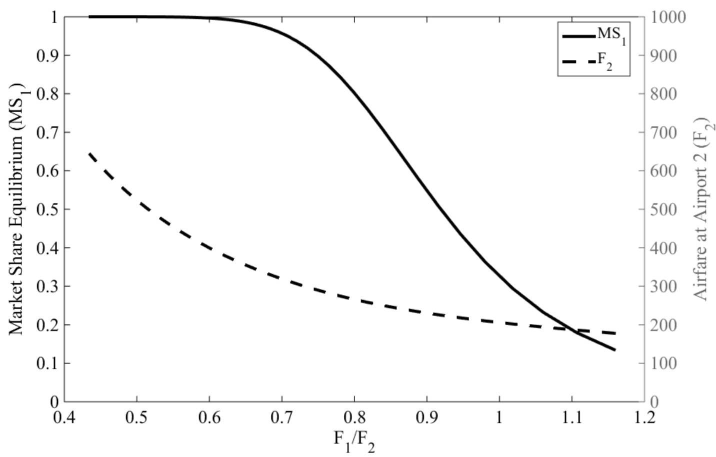

Figure 2 Market Share Equilibria With Respect To F_1/F_2

How does F_2 impact the airfare ratio? When F_2 decreases from \$600 to \$100, the ratio F_1/F_2 increases, reducing the equilibrium market share according to Figure 2. In fact, F_1 should decrease when F_2 does, according to Equation 4. However, the elasticity of F_1 with respect to F_2 (when $\$100 < F_2 < \$600$) is smaller than one according to Equation 4, so F_1 decreases at a slower rate than F_2. These results are based on an assumption (through the model coefficient values) that economies of density exist in airport services, insofar as a higher market share at an airport for a given destination will reduce airfare to that destination.

Impact of the Ground Access Distance (g_1 and g_2)

In this analysis, we use the numerical values presented in Table 1 but investigates the effects of several different ground access distances

(g_1 and g_2). We assume that Airport 2 is located 141 miles to the south of Airport 1, which is the driving distance from Jacksonville International Airport to Orlando International Airport. The relationship between g_1 and g_2 differs depending on whether a passenger begins their journey on the north or south side of Airport 1. As shown in Figure 3(a), for Point A which is located on the north side of Airport 1, $g_2 - g_1 = 141$ miles. For Point B located on the south side of Airport 1, $g_1 + g_2 = 141$ miles. Thus, the results with respect to g_1 on the north and south sides of Airport 1 are different, as shown in Figure 3(b). Both curves suggest that the equilibrium market share decreases as g_1 increases, meaning that MS_1 decreases as Point A is located farther north or Point B is located farther south to Airport 1. However, the reduction rate of such market share on the south side of Airport 1 is higher than on the north side. This is because for locations on the south side of Airport 1, when the ground access distance to the airport (g_1) increases, the ground access distance to Airport 2 (g_2) decreases.

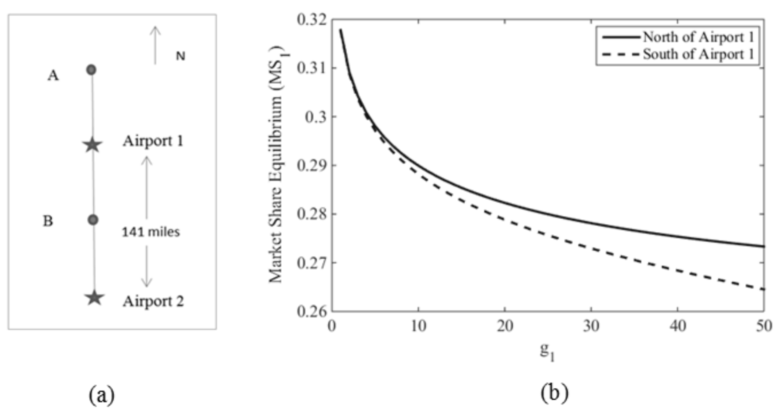

Figure 3 Market Share Equilibria With Respect To g_1 on North Side and South Side of Airport 1

Conclusion

A supply-demand feedback model was constructed by combining a binary logit model with an airfare regression model. It demonstrated how airfare, flight frequency, ground access distance could impact airport passenger leakage, when the market share at a local airport simultaneously impacts its airfare. A series of numerical analyses was conducted. Although only three numerical analyses are shown in this paper, the sensitivities of equilibrium market share with respect to other variables were also investigated (Fu, 2015) with the results in Table 2.

The findings of this paper demonstrate a positive feedback effect with respect to airport passenger leakage and airfares. In particular, the model demonstrates that when the local airport retains more passengers (that might otherwise "leak" to an out-of-region substitute airport), it will have lower airfares, which will further attract more passengers. It also shows that to increase local airport's passenger demand and to improve regional economic development, municipalities must consider the impact of airport competition from out-of-region hub airports in addition to providing better air services at the local airport.

Table 2 Sensitivities of MS_1

Feature	*If feature should*	*Then MS_1 at equilibrium will*
Weight of airfare (α)	↑	↓ / - / ↑
Weight of flight frequency (β)	↑	↓
Weight of ground access distance (γ)	↑	↑
Airfare at substitute airport (F_2)	↑	↑
Flight frequency at local airport (f_1)	↑	↑
Flight frequency at substitute airport (f_2)	↑	↓
Ground access distance to local airport (g_1)	↑	↓
Ground access distance to substitute airport (g_2)	↑	↑

In future work, this model may be populated by real data collected through a survey of air passengers. Firstly, the functional form and coefficients of the market share model can respectively be specified and estimated using survey data. Secondly, if out-of-region airport leakage is identified through a survey, the feedback model can be analyzed using real data for the variables, such as airfare, flight frequency, and ground access distance. Thirdly, when the supply-demand feedback model is applied to a specific airport, the geographic distribution of market share within the metropolitan area of the airport can be further explored.

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