Airport Marginal Cost Pricing: Discussion and an Application to Swedish Airports

Fredrik Carlsson[A]

Working Papers in Economics no. 85
December 2002
Department of Economics
Göteborg University

Abstract
We derive an optimal airport-pricing model, both with and without a constraint on the revenues, that includes all relevant external marginal costs,. Given the results of the model we discuss the implications on the profit of airports, and find that given that the proceeds of the environmental charges are seen as revenue for the airport, it is not obvious that a marginal cost-pricing scheme would result in financial deficits for the airports, this despite the reasonable assumption of increasing returns to scale in airport capacity. Using relatively crude estimates of the marginal costs, we compare the current pricing scheme with a marginal cost pricing scheme. We find that the effect on revenues of moving towards a marginal cost pricing scheme may not be so dramatic; especially not if the marginal external costs include estimated marginal costs of CO_2 emissions.

Key words: *Airport pricing, marginal cost pricing, emission charge.*

JEL-classification: H21, H23, R41, R48

I have received valuable comments and assistance from Francisco Alpizar, Lennart Bergbom, Håkan Brobeck, Malin Eriksson-Edgren, Olof Johansson-Stenman and seminar participants at the Department of Economics. Financial support from the Swedish Civil Aviation Administration and the Swedish Agency for Innovation Systems is gratefully acknowledged.

[A] Fredrik Carlsson, Department of Economics, Göteborg University, Box 640, 405 30 Göteborg, Sweden; Ph +46 31 7734174; Fax +46 31 773 10 43; E-mail fredrik.carlsson@economics.gu.se.

1. Introduction

In the case of airport pricing there is an interesting disparity between recommendations from economists based on efficiency arguments, and the actual implementation of pricing schemes. Economists tend to argue for a marginal cost pricing where an optimal charge is equal to the sum of marginal costs, including marginal external costs such as congestion and environmental damages. In most countries, airport charges are set equal to the average cost, although charges are also weight-based (see e.g. Doganis 1992; Martin-Cejas, 1997). This type of pricing is most likely due to the fact that the airports must recover their costs, and perhaps also due to difficulties in identifying the relevant marginal costs. In Sweden, there is some governmental subsidization of airport capacity, but to a large extent the airports are required to finance the infrastructure on their own. Under certain assumptions, it is not likely that average cost pricing is an efficient pricing scheme, not even under a cost-recovery restriction, although it has the advantage of being simple. Considering only average cost pricing versus marginal cost pricing, the current charges are most likely too high and an efficient use of the infrastructure is not encouraged. However, only a few countries include external costs such as environmental damages in their charges, and in these cases it is not clear that the full marginal external costs are included. A marginal cost pricing that includes all relevant costs may therefore result in higher charges than the current ones. Traditionally, in the aviation sector the environmental regulation has been of a command-and-control type with engine standards and phasing out of engine types. However, in the last few years, some countries have started to implement environmental considerations into their airport pricing. In addition, the European Union has recommended an increased use of incentive-based pricing of the transport sector (European Union, 2001). In this paper we develop a simple airport-pricing model that includes considerations of environmental damages and within this framework we discuss optimal pricing and the possibilities of cost recovery for the airport. Based on the model we develop an airport pricing scheme for Swedish airports and compare this with the current pricing scheme.

2. Optimal Marginal Cost Pricing

2.1 A Basic Model with Environmental Charges

There are a number of papers on optimal airport (runway) charges (e.g. Carlin and Park 1970; Levine 1969; Morrison 1983, 1987; Oum and Zhang 1990; Zhang and Zhang 1997). These mainly deal with the problem of congestion and the impact of profit requirements, or cost recovery, on the pricing scheme. The analysis and results are similar to the ones for optimal highway pricing (see e.g. Mohring 1970, 1976). Here we extend the optimal pricing problem to include consideration of the environmental external costs of air traffic. Throughout the paper an optimal charge is a charge that maximizes social welfare, defined as the unweighted sum of consumer and producer surplus and external costs. Following Zhang and Zhang (1997) we assume that social benefits of an airport infrastructure are:

$$SB = \sum_{ij} \int_0^{Q_{ij}} \left(c_{ij} + \theta D_{ij}(Q_j, K)\right) dQ_{ij} + \sum_{ij} c_{ij} Q_{ij} , \tag{1}$$

where Q_{ij} is number of flights of aircraft type $i, i \in I$, in period j and Q_j is the total number of flights in period j, i.e. $Q_j = \sum_m Q_{mj}$, $m \in I$. The full price of a particular flight, ρ_{ij}, is the sum of the airport charge, c_{ij}, and the delay cost, θD_{ij}, where θ is the monetary cost per unit of time delay, and D_{ij} is the delay in time units. The delay in time unit j is assumed to be a function of the total number of flights in time unit j, hence $D_{ij} = D_j$. Furthermore, we assume that the marginal delay cost is constant, i.e. independent of the delay time, although it can differ between passenger types. Social cost of the infrastructure is the sum of the full price, variable operating costs, $C\left(\sum_{ij} Q_{ij}\right)$, fixed capacity cost, Kr, where r is the unit capacity cost of the airport and K is the capacity (measured in for example maximum number of departures per time unit) and environmental costs, $\sum_{ij} Q_{ij} E_{ij}(D_j(Q_j, K))$, where E_{ij} is the marginal environmental cost for aircraft of type i at time period j:

$$SC = \sum_{ij} \left(c_{ij} + \theta D_{ij}(Q_j, K) \right) Q_{ij} + C\left(\sum_{ij} Q_{ij} \right) + Kr + \sum_{ij} Q_{ij} E_{ij}(D_j(Q_j, K)) . \tag{2}$$

Marginal environmental costs, E_{ij}, of aircraft i at time j is assumed to be a function of delay/congestion since, for example, delay increases fuel consumption and consequently increases emissions (see e.g. Johansson 1997).[1]

The airport authority sets charges and capacity so that social welfare is maximized:

$$\max_{c_{ij}, K} W = SB - SC . \tag{3}$$

For simplicity we assume that airport capacity is divisible. Further, to begin with we assume that there is no constraint on profits; the first order conditions are therefore

$$\left(-\theta \sum_m Q_{mj} \frac{\partial D_j}{\partial Q_j} \frac{\partial Q_j}{\partial Q_{ij}} + c_{ij} - \frac{\partial C}{\partial Q_{ij}} - E_{ij} - \sum_m Q_{mj} \frac{\partial E_{mj}}{\partial D_j} \frac{\partial D_j}{\partial Q_j} \frac{\partial Q_j}{\partial Q_{ij}} \right) \frac{\partial Q_{ij}}{\partial c_{ij}} = 0 , \tag{4}$$

$$\sum_{ij} Q_{ij} \left(\theta \frac{\partial D_j}{\partial K} + \frac{\partial E_{ij}}{\partial D_j} \frac{\partial D_j}{\partial K} \right) + r = 0 .$$

These two conditions determine the optimal charge and the optimal level of capacity. The optimal charge for aircraft type i in time period j is

$$c_{ij} = \frac{\partial C}{\partial Q_{ij}} + \theta Q_j \frac{\partial D_j}{\partial Q_j} + E_{ij} + \sum_m Q_{mj} \frac{\partial E_{mj}}{\partial D_j} \frac{\partial D_j}{\partial Q_j} . \tag{5}$$

The optimal charge is equal to the sum of marginal operating costs, marginal delay costs and marginal environmental costs, where the effect of delay on the emissions is also accounted for. Further, the optimal charge is differentiated between type of aircraft and time of day. This is a straightforward and expected result. However, one important question is if the airport, with this optimal pricing scheme, will recover its costs. This has been analyzed in detail before (see e.g. Mohring 1970; Morrison 1983; Zhang and Zhang 1997), and the answer depends on the functional form of the cost- and delay functions. The difference, however, is that in the present model it is assumed that the

---

[1] The risk of delays has two effects on fuel-consumption: consumption increases while in the stack, and more fuel is burned as a result of carrying the extra weight of the fuel (Somerville 1996).

proceeds from the environmental charge also go to the airport. Using the first order conditions, the profit for the airport can be written as

$$\Pi = \sum_{ij} \frac{\partial C}{\partial Q_{ij}} Q_{ij} - C\left(\sum_{ij} Q_{ij}\right) + \sum_{ij} Q_{ij}\theta\left(Q_j \frac{\partial D_j}{\partial Q_j} + K\frac{\partial D_j}{\partial K}\right) + \tag{6}$$
$$\sum_{ij}\left[Q_{ij}\left(\sum_m\left[Q_{mj}\frac{\partial E_{mj}}{\partial D_j}\frac{\partial D_j}{\partial Q_j}\right] + K\frac{\partial E_{ij}}{\partial D_j}\frac{\partial D_j}{\partial K}\right)\right] + \sum_{ij} Q_{ij}E_{ij}.$$

The sum of the first two terms is zero if the cost function is homogenous of degree one, i.e. under constant returns to scale for airport operating cost. Note that this is not likely to be the case; instead we should expect increasing returns to scale (Doganis, 1992), which implies that the sum of the first two terms is negative. If the delay function is homogenous of degree zero in traffic and airport capacity, then the third term will be zero.[2] However, Morrison (1987) suggests the following delay time function:

$$D_j = \frac{Q_j}{K(K - Q_j)};\ Q_j < K, \tag{7}$$

where D_j is the delay in hours and K is the hourly capacity of the runway.[3] With this formulation, the delay function is not homogenous of degree zero. We actually have that

$$Q_j \frac{\partial D_j}{\partial Q_j} + \frac{\partial D_j}{\partial K}K = \frac{-Q_j}{K(K - Q_j)} < 0, \tag{8}$$

so the third term in the profit function is most likely negative.

The fourth term is more problematic. To begin with, note that $\sum_i Q_{ij}\frac{\partial D_j}{\partial Q_j} + K\frac{\partial D_j}{\partial K} = kD_j$ if $D_j(Q_j, K)$ is homogenous of degree k. Under the somewhat extreme assumption that $\frac{\partial E_{ij}}{\partial D_j} = \frac{\partial E_{kj}}{\partial D_j}$ for all $i, k \in I$, i.e. that the effect of an increased delay on the marginal external cost is independent of aircraft type, we can write the fourth term as

---

[2] To see this note that if $D_j(Q_j, K)$ is homogenous of degree k, then $Q_j \frac{\partial D_j}{\partial Q_j} + K\frac{\partial D_j}{\partial K} = kD_j$.

[3] For notational simplicity we define hourly capacity of the runway as the capacity of the airport.

$$\sum_{ij}\left[Q_{ij}\frac{\partial E_j}{\partial D_j}\left(Q_j\frac{\partial D_j}{\partial Q_j}+K\frac{\partial D_j}{\partial K}\right)\right]. \tag{9}$$

In this case, if the delay time function is homogenous of degree zero, the fourth term is zero. Alternatively, if $\frac{\partial E_{ij}}{\partial D_j}\geq 1$ for all i, then the fourth term is strictly non-positive. Consequently, it is difficult to determine the sign of the fourth term; it is mainly an empirical issue. Finally, the fifth term of the profit function, $\sum_{ij}E_{ij}Q_{ij}$, is positive. Consequently, allowing the airports to collect the revenues from environmental charges can allow the airport to implement a marginal cost based charging system, and still earn non-negative profits. However, whether this is the case or not is to a large extent an empirical issue.

2.2 Optimal Marginal Cost Pricing with a Cost-Recovery Restriction

In order to ensure cost recovery the airport can impose a budget constraint restriction in its maximization problem. The airport would then face the following maximization problem

$$\max_{Q_{ij},K} W = SB - SC \tag{10}$$

$$\text{s.t. } \sum_{ij}c_{ij}Q_{ij} - C\left(\sum_{ij}Q_{ij}\right) - Kr = 0 .$$

For simplicity, we write the marginal external cost for departure ij, as $MEC_{ij}=\theta\sum_{k,k\neq i}Q_{kj}\frac{\partial D_k}{\partial Q_j}\frac{\partial Q_j}{\partial Q_{ij}}+E_{ij}+\sum_{m}Q_{mj}\frac{\partial E_{mj}}{\partial D_j}\frac{\partial D_j}{\partial Q_j}\frac{\partial Q_j}{\partial Q_{ij}}$. Differentiating the objective function with respect to the airport charge we have

$$\left(c_{ij}-\frac{\partial C}{\partial Q_{ij}}-\theta Q_{ij}\frac{\partial D_j}{\partial Q_j}\frac{\partial Q_j}{\partial Q_{ij}}-MEC_{ij}\right)\frac{\partial Q_{ij}}{\partial c_{ij}}+\lambda\left(Q_{ij}+c_{ij}\frac{\partial Q_{ij}}{\partial c_{ij}}-\frac{\partial C}{\partial Q_{ij}}\frac{\partial Q_{ij}}{\partial c_{ij}}\right)=0 . \tag{11}$$

Rearranging the first order conditions we than have

$$c_{ij} - \frac{\partial C}{\partial Q_{ij}} - \theta Q_{ij} \frac{\partial D_j}{\partial Q_j} \frac{\partial Q_j}{\partial Q_{ij}} - \frac{MEC_{ij}}{1+\lambda} = \frac{\lambda}{1+\lambda} \frac{\rho_{ij}}{\varepsilon_{ij}}, \tag{12}$$

where ρ_{ij} is the full price for departure *ij*, i.e. it is the sum of the airport charge and the delay cost, and ε_{ij} is the full price elasticity. This result is the standard Ramsey pricing result that the mark-up is inversely related to the full price elasticity (see e.g. Morrison 1987; Zhang and Zhang 1997). The difference is that the optimal charge is corrected for the marginal external costs.

2.3 The External-Cost Elements of the Airport Charge

The externality elements – noise, emissions and delay - of the airport charge are not as simple as we have presented them so far. The environmental elements of the airport charge are more complex since the external cost depends on factors such as the population density around the airport, the aircraft (engine) type and, for noise pollution, the time of day. The dose-response relation may not be linear, and hence the marginal cost could depend on the amount of air traffic. Furthermore, there are uncertainties regarding the marginal value of reductions of emissions, in particular for global emissions.

Regarding delay (congestion) costs there is one important difference between road and airport congestion. In the case of air travel, the passengers buy tickets from an airline. As shown by Brueckner (2002, 2003), an airline internalizes the congestion costs it imposes on itself, including the delay time for its own passengers.[4] This means that if there is only one airline operating at an airport, the optimal delay/congestion charge is zero. Further, if there is more than one airline, the optimal charge for a particular airline should only reflect the external cost on other airlines and their passengers. However, a differentiation among airlines is likely to cause legal problems. It is doubtful whether it is possible to implement such a charge. In this respect, other solutions are desirable. One interesting alternative is to allow for slot trading (see e.g.

---

[4] This holds under the conditions that the airlines can price discriminate and that all passengers have the same value of time. If these conditions are not satisfied, the results are weakened although some internalization still occurs.

Borenstein 1988; Starkie 1994). The basic idea behind slot trading is that slots are allocated efficiently since they are allocated to the airline that has the highest willingness to pay. However, with slot trading there is an inherent risk of distorted competition among airlines.[5]

2.4 Extensions

There are several extensions that can be made to the above model. We will not formalize the extensions, although it would be fairly straightforward to do so. Instead we briefly discuss the implications of the extensions.

Airport capacity is not divisible. In the case of indivisible expansion Oum and Zhang (1990) show that the congestion charge exceeds the annualized capacity cost in periods with capacity shortage, and falls short of the capacity cost under periods with excess capacity. In addition, Zhang and Zhang (2001) show that with an increase in traffic over time, a social optimal pricing can involve a financial deficit in the beginning and a surplus in later years (still achieving cost recovery in the long run).

The aeronautical activities are not the only source of income for an airport; there are also large concession revenues from commercial activities. Zhang and Zhang (1997) show that with constant returns to scale in concession operations, the optimal charge implies a subsidization of aeronautical operations from concession operations. Although, the subsidization may not be sufficient to restore marginal cost pricing of the aeronautical activities. The intuition of the results is simple: moving from a case without subsidization, and hence Ramsey pricing of the aeronautical service and marginal cost pricing of the commercial activity, it is welfare enhancing to reduce the price of the former activity and increase the price of the latter.

Finally, the analysis has not considered the fact that competition may be imperfect; instead it was implicitly assumed that there was perfect competition. This can create a problem since the airport charge has an impact on prices, quantities and market shares. Even if the airport is not concerned with these welfare effects, they indirectly have to be considered since they also affect emissions from aviation. This implies that it may be optimal to deviate from marginal cost pricing due to imperfect competition. The problem is however two-fold. First of all it is not obvious whether the optimal charge is

---

[5] See Dotecon (2001) and Lévêque (1998) for discussions on how to implement an efficient slot trading mechanism.

higher or lower than the marginal costs. The reason is that a charge can shift output between firms (for a detailed analysis see e.g. Carlsson 2000, 2002). Second, estimating the magnitude of the optimal deviation from marginal cost pricing requires knowledge about demand and supply elasticities.

2.5 Problems with Marginal Cost Pricing

Besides the cost-recovery restriction, there are other problems with marginal cost pricing; see e.g. Rothengatter (2001) and Nash and Matthews (2001) for recent critical discussions. With indivisibility in airport capacity, the user charges will fluctuate over time. This may have negative effects in itself, and may not be politically feasible. Another type of critique concerns the institutional setting. For example, since the revenues from the user charges can be higher when capacity is too small, the incentives from infrastructure investments might be distorted. There are also, as we have discussed, strong informational requirements for calculating the optimal charges. Finally, when deriving the optimal pricing scheme we have implicitly assumed that there is marginal social cost pricing in the rest of the economy as well. If this is not true, it is no longer clear what the socially optimal pricing scheme would be. However, from an efficiency point of view it is not clear what the effects of for example a subsidization of rail infrastructure would have on the pricing scheme. If, for example, the government finances the fixed costs of the rail infrastructure, and marginal cost pricing is applied in that sector, the efficient solution would be a marginal cost pricing (with a cost recovery restriction) also in the aviation sector. However, if the railway sector were so heavily subsidized that the charges are below marginal cost, the optimal charges in the aviation sector would also, most likely, be lower.

3. Marginal Costs at Swedish Airports

3.1 Operating and Capacity Costs

The two major costs for Western European airports are labor costs and capital costs. These two costs taken together represent approximately 60% of the total airports costs at European airports (Doganis, 1992). The labor cost varies largely among airports, since it depends on whether the airport is involved in activities such a baggage handling, duty-free shops and freight handling. According to Doganis (1992) there is empirical evidence that there are economies of scale in airport operations but that when the airport expands, unit-operating costs initially tend to increase. There are relatively few, publicly available, studies of airport costs. Two recent studies are Himanen et al. (2002) and Luftfartsverket (2000), studying the infrastructure costs at Helsinki-Vantaa airport and at major Swedish airports, respectively. Here we extend the work of Luftfartsverket (2000), in particular by including a longer time-series. Data on total costs for the passenger and landing service were obtained for the years 1993 to 2001, covering 19 airports owned by the Swedish CAA. However, in order to estimate the marginal costs for landings, additional information would be necessary, since it is likely that the marginal costs of landings depends on the type of aircraft and other factors. We therefore focus on the passenger costs. It should be noted that the available data on passenger costs is also very limited, and more detailed information would have been desirable.

We estimate a fixed-effects model with the total cost in 2001 prices as dependent variable. Testing for functional form, a PE-test (Verbeek, 2000) between a linear and a log-log cost function results in inconclusive results, since neither of the functional forms can be rejected. However, the log-log functional form passes a RESET test (Verbeek, 2000) and the results are robust to the sample. The linear functional form does not pass a RESET test, and perhaps more important, the results are very sensitive to the sample. We therefore opt for the following functional form of the cost function for airport j:

$$C_j = \exp(\alpha_j)\left(Pax_j\right)^{\beta}, \tag{13}$$

where C_j is the total cost for the passenger service, Pax_j is the number of passengers, and α_j and β are parameters to be estimated. In addition, a dummy variable for the last year (2001), is included among the independent variables; this year turned out to have a significant impact on the estimated relationship. The results of the estimations are presented in Table 1 below.

Table 1. Total cost function passenger service, fixed effects not reported. Dependent variable: the log of Cost for passenger service in SEK 2001 prices. White corrected standard errors.

Variable	*Coefficient*	*P-value*	*Nobs.*	R^2	*RESET* $\sim \chi^2_{a,3}$
Ln(Pax_j)	0.467	0.011	171	0.96	6.41
Year 2001	0.244	0.005			
			MC (USD)	P-value	Average Pax
Arlanda	12.674	0.000	3.171	0.012	7646420
Bromma	10.101	0.000	1.140	0.012	418101
Landvetter	11.662	0.000	2.561	0.012	1713750
Sturup	11.329	0.000	2.682	0.011	841427
Halmstad	9.611	0.000	1.751	0.010	746393
Ronneby	8.990	0.000	0.792	0.011	103098
Ängelholm	8.904	0.000	0.564	0.013	166103
Jönköping	10.648	0.000	3.843	0.012	119551
Kalmar	9.967	0.000	1.995	0.012	113991
Karlstad	9.798	0.000	1.634	0.008	120859
Kiruna	8.924	0.000	0.866	0.016	770613
Luleå	10.180	0.000	1.210	0.012	434367
Norrköping	9.492	0.000	1.339	0.011	989153
Skellefteå	10.137	0.000	2.386	0.011	112139
Sundsvall	10.126	0.000	1.622	0.016	226359
Umeå	10.062	0.000	1.221	0.013	341753
Visby	9.693	0.000	1.252	0.011	163492
Örnsköldsvik	8.863	0.000	0.855	0.011	704752
Östersund	9.351	0.000	0.816	0.121	192201

The parameter estimates imply that marginal cost for passenger service is approximately 47% of the average cost. Furthermore, for a given airport, average and marginal costs decrease with increases in the number of passengers. Note, however, that we cannot directly compare airports, since the cost at a specific airport also depends on the airport specific fixed effect. The estimated fixed effects reveal that the three large airports, Arlanda, Landvetter and Sturup, have a higher marginal passenger cost for a given level of passengers. For each airport the marginal costs, in USD,[6] are calculated using the estimated parameters and the mean volume of the number of passengers for each airport.[7] The estimated marginal costs are lower than the current passenger charges, although they are perhaps higher than expected. However, it is doubtful whether we have succeeded in estimating the short-run marginal passenger cost. In order to estimate the short-run marginal cost, much more detailed information would be required.

---

[6] The exchange rate is 1 USD=10 SEK.

[7] Note that the reported marginal costs are calculated setting the time dummy variable equal to zero.

3.2 Delay Costs

There are only capacity problems only at Arlanda airport, in particular during peak hours. The delay costs during peak hours are not only a result of insufficient runway capacity, but also factors such as terminal capacity and number of gates. The runways at Arlanda airport are used both for domestic and international departures. However, in this paper we focus on domestic departures, and are therefore not concerned with the marginal external cost on international departures, nor the external delay cost on domestic travelers resulting from international departures. Focusing on the traffic at peak hours, it is clear that the delay cost and the marginal delay cost approach infinity as the number of departures approaches the capacity. For example, using the specification in Morrison (1987) we have that the marginal delay cost in time period *j* depends on the runway capacity, the number of departures in time period *j* and the passengers' opportunity cost of time

$$\theta Q_j \frac{\partial D_j}{\partial Q_j} = \frac{\theta Q_j^2}{(K - Q_j)^2} . \tag{14}$$

As we have discussed, it is however reasonable to assume that airlines internalize a part of this delay cost. Following Brueckner (2002,2003) we assume that airlines internalize the congestion costs they impose on themselves. Consequently, if only one airline operates in time period *j*, the external delay cost is zero. Unfortunately, it is not reasonable to assume that such a delay charge is possible to implement in practice. In order to illustrate the potential costs of the congestion problem at Arlanda, we still calculate the marginal external cost for domestic traffic at different utilization levels. First of all, for simplicity we assume that the share of domestic departures is 50%. Regarding the opportunity cost of time we will rely on the official values for transport infrastructure investments in Sweden (Swedish Institute for Transport and Communication Analysis, 2000); these values are based on stated preference surveys on the value of time (Algers et al. 1995, 1998). The relevant value of time in this context is the value of delay time; for leisure travel this is estimated to \$13 per hour and for business travel \$22 per hour. Finally, we assume that the average seat capacity is 100 seats, that the average load factor is 65% and that 50% of the passengers are business passengers. The current runway capacity at Arlanda is 73 departures per hour. The table below contains the marginal delay cost imposed by one flight for a certain airline at different levels of number of departures and market shares of the airline.

Table 2. Marginal delay cost in USD imposed by one flight at different airline market shares and different rates of capacity utilization.

Market share	*Number of departures*				
	72	70	68	66	64
90	398	43	15	7	4
80	796	86	30	15	9
70	1193	129	45	22	13
60	1591	172	60	30	17
50	1989	215	75	37	22
40	2387	258	90	45	26
30	2785	301	105	52	31
20	3182	344	120	59	35
10	3580	387	135	67	39

If an airline has a substantial market share, it is only at close to full capacity utilization that the marginal delay cost becomes substantial. On the other hand, for an airline with a small market share, this cost becomes very high at high capacity utilization. Even if it is difficult to implement a socially optimal delay pricing, the estimated costs suggest that there are welfare gains from reducing congestion. Note that it is not certain, not even reasonable, that the capacity use would remain unchanged if a delay charge were introduced. The equilibrium charge would therefore depend on the equilibrium capacity utilization. Furthermore, the optimal charge would depend on the time of day, i.e. at peak hours the charge would be higher than at off-peak.

3.3 Noise

There are a number of studies assessing the value of aircraft noise nuisances. A major part of these studies are hedonic price studies (e.g. Nelson 1980; Levesque 1994; Uyeno et al. 1993; Pennington et al. 1990); but there are also studies using the contingent valuation method (Feitelson et al. 1996) and similar stated preference methods (van Praag and Baarsma 2000). Regarding the hedonic price studies, the results of course vary, but most studies find a noise depreciation index around 0.5-0.7, i.e. if the noise nuisance increases by, say, 10 units, property prices would decrease by 5-7%.

One problem with the hedonic price studies is that they do not estimate the marginal value of the characteristics (at least not the studies referred to in this paper). Instead, the studies measure the marginal impact of noise nuisance on the equilibrium property price. Although it is possible in principle to estimate the marginal value of the characteristics using the hedonic price method, this is usually not done due to data availability. An alternative solution is to impose rather strict restrictions on individuals' preferences, making it possible to interpret the results from the hedonic price studies as marginal values. A second problem with the hedonic pricing method is that it only measures use values, since passive use values by definition are not reflected in property values. In the case of noise nuisance, this may not be an important problem since passive use values for noise are likely to be small. In any respect, it is rather difficult to use the results from the hedonic pricing studies to determine the marginal value of noise nuisances. An alternative approach would be to use a stated preference survey to assess the value of noise nuisances. Perhaps surprisingly, not many stated preference surveys have been undertaken on airport noise. More importantly, there are no reliable estimates of external noise costs of air traffic at Swedish airports, let alone any available data for calculating marginal external noise costs of different aircraft at different airports and times of day. It is therefore not possible for us to calculate the relevant external noise cost in this paper.

3.4 Environmental Damages

The first problem when estimating the environmental costs of aviation is to estimate the amount of emission for different flights. We use the emission data bank for civil aviation in Sweden developed by the Swedish CAA and the Swedish Defense Research Agency (Luftfartsverket, 2000).[8] From this database total emission and LTO emission can be estimated for a number of different aircrafts and routes. The table below contains information about emission from the most common aircraft types for a flight between Stockholm-Arlanda (ARN) and Gothenburg-Landvetter (GOT), and between Stockholm-Arlanda and Luleå-Kallax (LLA).

---

[8] For details on the emission database, see FFA (2000).

Table 3. Emissions and fuel consumption per flight for flights from Stockholm-Arlanda to Gothenburg-Landvetter and Luleå-Kallax; load factors are 65%.

Aircraft	*Emissions*								
	Flight Total					LTO			
	Fuel (tone)	CO_2 (tone)	NO_x (kg)	HC (kg)	CO (kg)	CO_2 (tone)	NO_x (kg)	HC (kg)	CO (kg)
	Arlanda - Landvetter								
B737-600	1.53	4.8	14.04	2.67	33.69	1.09	3.03	0.77	6.96
DC9-41	2.23	7.1	24.32	4.59	20.33	1.5	4.13	1.64	6.53
MD-81	2.41	7.6	36.7	3.53	11.06	1.63	6.72	0.79	2.51
	Arlanda - Kallax								
B737-600	2.16	6.8	19.19	3.08	49.56	1.10	3.06	0.77	6.99
DC9-41	3.11	9.8	30.99	6.24	30.67	1.52	4.23	1.65	6.54
MD-81	3.35	10.6	47.46	5.62	16.58	1.65	6.86	0.79	2.51

We use the official values for transport infrastructure investments in Sweden for valuation of the regional environmental effects (Swedish Institute for Transport and Communication Analysis, 2000). The shadow values are estimated to \$6/kg NOx and \$3/kg HC. For CO_2 emissions and global environmental effects, we simply use the current (year 2002) household tax level of 0.053 USD/kg CO_2, which is also often used as a shadow price of CO_2 emissions in Sweden. Given these shadow prices we can calculate the marginal environmental cost for different flights. Since there is a discussion regarding the possibilities of a fuel charge, i.e. a charge on CO_2 emissions, we calculate the marginal cost with and without considering CO_2 emissions.[9]

Table 4. Marginal environmental cost in USD per flight for flights from Stockholm-Arlanda to Gothenburg-Landvetter and Lulelå-Kallax; load factors are 65%.

	Arlanda-Landvetter			*Arlanda-Kallax*		
	B737-600	DC9-41	MD-81	B737-600	DC9-41	MD-81
Regional emissions	92.25	159.69	230.79	124.38	204.66	301.62
CO_2 emissions	254.4	376.3	402.8	360.4	519.4	561.8
Total	346.65	535.99	633.59	484.78	724.06	863.42
Landing- takeoff, excluding CO_2	20.49	29.7	42.69	20.67	30.33	45.53
Landing- takeoff, including CO_2	78.26	109.2	129.08	78.97	110.89	130.98

---

[9] An additional reason is that there are large uncertainties both regarding the impact of CO_2 emissions from aviation and the evidence on global warming and the role of man-made emissions, see for example Michaels and Balling (2000).

4. The Swedish Airport Charge

4.1 The Current System

The current pricing system at Swedish airports is an average cost pricing scheme, which to a large extent is due to the need to cover the costs of the airport. There have been discussions about implementing a marginal cost based pricing scheme. The charge is weight-based, as in many other countries. The landing charge has been, and is, a major source of revenue for airports in Europe, in addition to the revenues from passenger charges (Martin-Cejas 1997). The total charge consists of a landing, terminal navigation (TNC), enroute, passenger, noise and emission charge (Luftfartsverket 2002). The charge is differentiated on aircraft weight and airports, and the TNC is also differentiated on aircraft weight. The passenger and security charges are differentiated among airports and among domestic and international passengers.[10]

Within the European Union there have been discussions about implementation of airport charges related to the noise impact. Through the work of the group for Abatement of Nuisances Caused by Air Transport (ANCAT) a proposal of a noise charge has been put forward by the Commission of the European Communities (European Union 2001). This type of noise charge has been implemented at Swedish airports (Luftfartsverket 2000). The noise charge depends on the aircraft's certified noise level in accordance with ICAO Annex 16 Volume 1 and applies to aircrafts over 9 tonnes. The charge for aircraft *i* at airport *j* is calculated as

$$NC_{ij} = c_j \left[10^{(La_i - Ta_j)/10} + 10^{(Ld_i - Td_j)/10} \right], \tag{15}$$

where c_j is the unit noise charge for airport *j*, La_i is the certified approach level for aircraft *i* and Ld_i is the certified average sideline and take-off level for aircraft *i*. Ta_j and Td_j are the minimum thresholds for airport *j*. The threshold values are the same for all airports and are 91 EPNdB for arrivals and 86 EPNdB for departures, respectively. The unit noise charge varies between airports. For Arlanda the current unit noise charge

---

[10] The current levels of the charges are reported in Luftfartsverket (2002). In addition the security charge was increased in July 2002 (personal communication). The increase in the security charge was quite dramatic. For example, the charge per domestic passengers at Arlanda airport increased from 5 SEK to 17 SEK.

is $3 and the maximum total charge is $60. The design of this charge is essentially not related to the marginal external cost of noise.

The emission charge depends on the aircraft's certified emission data in accordance with ICAO Annex 16 Volume 2 and applies to aircraft over 9 tonnes (Luftfartsverket 2000b). The emission charge differentiates among seven types of aircraft engines, where the classification is based only on emissions of nitrogen oxides and hydrocarbons during landing and takeoff. The charge is furthermore differentiated on the landing charge. The table below reports the current environmental charges at Swedish airports. The table also contains information about the classification of different aircraft types – in practice this varies with the type of engine. The classifications shown are for the most common engine type.

Table 5. The design of the emission charge at Swedish airports

Charge class	*Example aircraft type*	*LTO emissions, g/KN*	*Increase in landing charge*
0	DC9-41	> 19 g/KN HC or > 80 g/KN NOx	30%
1		< 19 g/KN HC and ≤ 80 g/KN NO_x	25%
2	MD81	< 19 g/KN HC and ≤ 70 g/KN NO_x	20%
3		< 19 g/KN HC and ≤ 60 g/KN NO_x	15%
4		< 19 g/KN HC and ≤ 50 g/KN NO_x	10%
5	B737-600, B146-200	< 19 g/KN HC and ≤ 40 g/KN NO_x	5%
6	Dash 8-400, Saab 340	< 19 g/KN HC and ≤ 30 g/KN NO_x	0%

It is interesting to note that for example the DC9-41 is classified as the worst charge class, due to the high amount of HC emissions during landing and take-off. Compared to for example the MD81, which according to our calculations in Section 3 has a higher marginal damage cost, the DC9-41 is still worsely ranked.

4.2 Changes in the current system

In order to illustrate the changes in the charge system, we calculate current and new charges for a number of flights between Arlanda and Landvetter and between Kallax and Landvetter. For all flights we assume a load factor of 65%.[11] Of particular interest is the relation between the revenues from the emission charge and the other charges. We report the results for with and without inclusion of CO_2 damages. As we showed in

---

[11] Passenger and security charges are based on the departing airport, while other charges are based on the destination airport. All calculations are based on the following assumptions regarding number of seats: B737-600, 103 seats; DC9-41, 122 seats; and MD-81, 133 seats.

Table 1 our estimated marginal passenger costs are, with some exceptions, the highest for the three largest airports. However, the marginal passenger cost is still, even for these airports, lower than the current charge. For example, the charge per domestic passenger at Arlanda is today 5.2, while we estimate the marginal cost to 3.2. For most other airports, the current passenger charge is even much higher than our estimated marginal passenger cost. The charge per domestic passenger at Luleå Airport (Kallax) is today 4.7, while we estimate the marginal cost to be 1.2. In addition, even if we have not been able to estimate the marginal cost for landing, we expect it to be smaller than the current charge. Consequently, we expect that moving from the current charge system to a marginal cost pricing system would result in lower revenues from the passenger and landing charge. At the same time, the current emission charges should be increased if they are to reflect marginal damage costs. Even if only regional and local emissions are considered, the emission charge will increase substantially. As discussed, there will also be a change in the relative level of the emission charge among aircrafts, since our estimated marginal external cost is higher for the MD-81 than the DC9-41, while the current charge system, due to its focus on HC emission, results in a higher charge for the DC9-41.

Let us for simplicity assume that the current charge system results in profit break-even for each airport. From the last column of Table 6 we can then see if the suggested changes would also result in profit break-even. For the trip between Arlanda and Landvetter, this holds, even if the emission charge does not include CO_2 emissions; for the other case a CO_2 charge would have to be included. This is if of course due to the fact that our estimated marginal passenger cost is much lower for all airports except the three largest airports.

However, there are reasons to believe that the current charges related to security, TNC and landing are higher than the corresponding marginal cost. Implementing marginal cost pricing is therefore likely to reduce the charge more than indicated in the Table below. In that case, an emission charge that does not include CO_2 emission would never result in financial break-even. However, if the emission charge would include CO_2 emissions, and given that it would be based on our assumed value of CO_2 emissions, there is a clear possibility of financial break-even.

Table 6. Current and new pricing schemes, all prices in USD, for different flights between different airports.

			Pax	*Emission*	*Other*	*Sum*
ARN - GOT	B748-600	Current	348.1	12.1	462.2	822.4
		New I	212.3	92.3	462.2	766.7
		New II	212.3	346.6	462.2	1021.1
	DC9-41	Current	412.3	71.5	477.6	961.4
		New I	251.3	156.7	477.6	885.7
		New II	251.3	536.0	477.6	1265.0
	MD-81	Current	449.5	62.6	585.3	1097.4
		New I	274.1	230.8	585.3	1090.2
		New II	274.1	633.6	585.3	1493.0
LLA - ARN	B748-600	Current	314.7	13.8	562.0	890.4
		New I	120.5	124.4	562.0	767.4
		New II	120.5	484.8	562.0	1127.8
	DC9-41	Current	372.7	81.1	588.9	1042.7
		New I	142.7	204.7	588.9	889.5
		New II	142.7	724.1	588.9	1399.0
	MD-81	Current	406.3	71.8	717.0	1186.0
		New I	155.6	301.6	717.0	1124.2
		New II	155.6	863.4	717.0	1676.0

5. Conclusions

The current Swedish airport charge system is more or less of an average cost pricing type. Therefore, reforming the system towards a marginal cost pricing would most likely result in lower revenues for the airports. At the same time a marginal cost pricing would likely result in efficiency gains. The current emission and noise charges at Swedish airports reflect, to some extent, differences in marginal external costs among aircrafts and airports, but compared to our estimated marginal external costs they are too low. Hence, by introducing a marginal cost pricing that reflects the marginal external costs, the effects on the airport revenues may not be so dramatic. We have shown that an emission charge that does not include CO_2 emissions most likely will not result in the same amount of revenues as today. This does not necessarily mean that the marginal cost pricing is not desirable. First of all, the deficit could be financed via tax revenues. Second, it could be possible to introduce a Ramsey type of pricing scheme. In any respect, more research and more detailed information is necessary in order to be able to estimate the relevant marginal costs in the first place.

References

Algers, S., B. Hugosson and J. Lindqvist Dillén (1995) *1994 års tidsvärdesstudie.* Stockholm: Transek Consultancy.

Algers, S., P. Bergström, M. Dahlberg and J. Lindqvist Dillén (1998) Mixed logit estimation of the value of travel time. Working Paper 1998:15, Department of Economics, Uppsala University.

Borenstein, S. (1988) On the Efficiency of Competitive Markets for Operating Licenses. *Quarterly Journal of Economics* 103, 357-385.

Brueckner, J. (2002) Internalization of airport congestion. *Journal Air Transport and Management* 8, 141-147.

Brueckner, J. (2003) Airport congestion when carriers have market power. *American Economic Review*, forthcoming.

Carlin, A. and R.E. Park (1970) Marginal cost pricing of airport runway capacity. *American Economic Review* 60, 310-319.

Carlsson, F. (2000) Environmental Taxation and Strategic Commitment in Duopoly Models. *Environmental and Resource Economics* 15, 243-256.

Carlsson, F. (2002) Environmental Charges in Airline Markets. *Transportation Research Part D* 7, 57-73.

Doganis, R. (1992) *The Airport Business*. London: Routledge.

Dotecon (2001) Auctioning Airport Slots. A report for HM Treasury and the Department of the Environment, Transport and the Regions. January 2001.

European Union (2001) Proposal for a Directive of the European Parliament and of the Council on the Establishment of a Community Framework for Noise Classification of Civil Subsonic Aircraft for the Purposes of Calculating Noise Charges. COM (2001) 74 Final.

Feitelson, E., R. Hurd and R. Mudge (1996) The impact of airport noise on willingness to pay for residences. *Transportation Research D* 1, 1-14.

FFA (2000) Methods for Computing Exhaust Emissions from Aircraft: Description and Validation, FFA TN 2000-14

Himanen, V., T. Idstrom, A. Gobel and H. Link (2002) Annex 5e: Helsinki-Vantaa Airport, in Unifications of Accounts and Marginal Costs for Transport Efficiency, Deliverable 10: Infrastructure Cost Case Studies.

Johansson, O. (1997) Optimal road-pricing: Simultaneous treatment of time losses, increased fuel consumption and emissions. *Transportation Research Part D* **2**, 77-87.

Levesque, T. (1994) Modeling the effects of airport noise on residential housing markets. *Journal of Transport Economics and Policy* **28**, 199-210.

Lévêque, F. (1998). Insights from micro-economics into the monetary trading of slots and alternative solutions to cope with congestion at EU airports. CERNA Working Paper, 1998.

Levine, M.E. (1969) Landing fees and the airport congestion problem. *Journal of Law and Economics* 12, 79-108.

Luftfartsverket (2000). Översyn av förutsättningar för marginalkostnadsprissättning inom luftfartssektorn. Delredovisning till SIKAs regeringsuppdrag lämnat av Luftfartsverket. LFV Ekonomi/Finans rapport.

Luftfartsverket (2002). Luftfartstaxa för Luftfartsverkets flygplatser. Norrköping: Luftfartsverket

Martin-Cejas, R. (1997) Airport pricing systems in Europe and an application of Ramsey pricing to Spanish airports. *Transportation Research E* 33, 321-327.

Michaels, P. and R. Balling (2000), The Satanic Gases. Clearing the Air about Global Warming, Washington, D.C.: Cato Institute.

Mohring, H. (1970) The peak load problem with increasing returns and pricing constraints. *American Economic Review* 60, 693-705.

Mohring, H. (1976) *Transportation Economics*. Cambridge, MA: Ballinger.

Morrison, S. (1983) Estimation of long-run prices and investment levels for airport runways. *Research in Transportation Economics* 1, 103-130.

Morrison, S. (1987) The equity and efficiency of runway pricing. *Journal of Public Economics* 34, 45-60.

Nash, C. and B. Matthews (2001) Why reform transport prices? A review of European research. Working Paper, Institute of Transport Studies, University of Leeds.

Nelson, J.P. (1980) Airports and property values: A survey of recent evidence. *Journal of Transport Economics and Policy* 14, 37-52.

Oum, T. and Y. Zhang (1990) Airport pricing. Congestion tolls, lumpy investment, and cost recovery. *Journal of Public Economics* 43, 353-374.

Pennington, G., N. Topham and R. Ward (1990) Aircraft noise and residential property values adjacent to Manchester international airport. *Journal of Transport Economics and Policy* **24**, 49-59.

Prag, B. van and B. Baarsma (2000) The shadow price of aircraft noise nuisance, Working Paper, University of Amsterdam.

Rothengatter, W. (2001) How good is first best? Marginal cost and other pricing principles for user charging in transport. Working Paper, University of Karlsruhe.

Starkie, D. (1994) Developments in Transport Policy: the US Market in Airport Slots. *Journal of Transport Economics and Policy* 28, 325-329.

Swedish Institute for Transport and Communications Analysis (1999). Översyn av förutsättningarna för marginalkostnadsbaserade avgifter i transportsystemet, SIKA Rapport 1999:.

Swedish Institute for Transport and Communications Analysis (2000). Översyn av förutsättningarna för marginalkostnadsbaserade avgifter i transportsystemet, SIKA Rapport 2000:10.

Somerville, H. (1996) Airlines, aviation, and the environment. In Cartledge, B. (ed.), *Transport and the Environment*, Oxford: Oxford University Press.

Uyeno, D., S. Hamilton and A. Biggs (1993) Density of residential land use and the impact of airport noise. *Journal of Transport Economics and Policy* **27**, 3-18.

Verbeek, M. (2000) *A Guide To Modern Econometrics*. Chichester: John Wiley.

Zhang, A. and Y. Zhang (1997) Concession revenue and optimal airport pricing. *Transportation Research E* 33, 287-296.

Zhang, A. and Y. Zhang (2001) Airport charges, economics growth, and cost recovery. *Transportation Research E* 37, 25-33.