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WORKPACKAGE 7: CASE STUDY 7h

MOHRING EFFECTS FOR AIR TRANSPORT

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Executive summary

- The main objectives pursued in this work are the following: (i) discuss the applicability of the concept of Mohring effects for air transport; (ii) evaluate empirically the importance of these effects for the European air market; and (iii) provide a methodological approach which can be transferred to the context of other transport modes with scheduled services.
- The Mohring effect was originally discussed in the context of the bus industry (Mohring, 1972). For buses, the Mohring effect relates to the reduction of waiting times at bus stops. Even if in other transport modes the arrival of vehicles to pick passengers does not share the stochastic nature of buses, which are affected by changing road and traffic conditions, there might exist effects of similar nature.
- When air carriers alter their frequencies as a response to changes in demand conditions, passengers' generalised cost vary for two reasons: (a) travel times might change as a result of the introduction/elimination of indirect flights, (b) passengers are forced to adapt their preferences to the new flight schedules. Hence, the total Mohring effect in air transport may be interpreted as the resulting changes in travel times (t_i) and adjustment-to-schedule times (t_{as}), after a change in airlines' flight schedules.
- Time t_i is calculated as the difference between the programmed departure time and the arrival time at final destination. Thus, for direct flights t_i will represent time 'in-the-plane', while for indirect flights (connecting at an intermediate stop), it is time 'in-the-journey', including all those times that the passenger spends in the planes plus time at connecting airports. Adjustment-to-schedule time t_{as} may be calculated under some simplifying assumptions as the difference between preferred departure times and the actual schedules offered by companies.
- Total Mohring effect per passenger (time gains or losses) is then given by: $Dt_i + Dt_{as}$, where D represents changes in time between periods of reference 1990 and 1998.
- Three type of results are obtained in this work. First, for each route the magnitude of total Mohring effects has been evaluated, which allows to provide information on the situation for the passengers in that route, and also to perform some analysis by airports. Second, total time savings derived from passengers in the sample chosen are calculated. This allows to provide an estimate of the importance of Mohring effects. Third, marginal Mohring effects caused by the entry of new passengers in a given route are estimated.
- There exist some limitations associated to the translation into monetary terms of time savings (marginal and total) derived from our results. The reasons are: (i) the international nature of our sample of routes; (ii) the different nationalities of travellers within the routes; and (iii) the different reasons for flying (business, leisure). We present monetary results on the basis of UNITE conventions, with a caveat of the representativeness of those figures for the context of particular routes.
- The sample used to obtain data is formed of 26 European airports. The criterion followed for airports' selection was to have at least one airport for each EU Member

State, plus Norway and Switzerland. From the 650 potential origin/destination pairs that could be in principle formed with the selected airport, 469 routes were finally chosen for the analysis. Some of the potential o/d pairs do not have in practice any direct or indirect service so they could not be included, while others presented problems to obtain the required information.

- Some of the routes included in the sample do not have information on volume of passengers. On the other hand, not all data on passengers can be regarded as reliable information. Therefore, for the calculation of marginal Mohring effects, a sub-sample of 236 routes was used after a filtering process.

- Average length of intra-European routes in the sample is 1,170 km, with an average density of 160,000 passengers per year. Taking only those routes with data on passengers, the sample represents in 1998 a total movement of around 51 million passengers.

- Regarding changes in the supply of air transport services, the global picture is one of an increase in the average number of weekly flights, around 27% for total flights (from 52.3 flights on average per route in 1990 to 66.5 in 1998). This larger supply of flights is basically formed of more direct connections, which increase from 28.6 to 43.9 (53%), while indirect flights have experienced a relatively small reduction, from 23.6 to 22.6 (-4%). Although most routes have experienced an increase in supply between 1990 and 1998, some lengthy low-density routes have experienced flight reductions.

- A representative air traveller flying within Europe's main capitals in 1998 had on average a gain of 20 minutes compared to the situation in 1990. This is the positive externality received by passengers from the existence of denser air routes. The global result is that European air travellers obtained a total gain between 1990 and 1998 close to 20.9 million hours (€ 325.6 million) , calculated under the assumptions of this work.

- Airports have been grouped according to similar changes in the supply of flights in the routes departing from them. The groups thus formed are: (a) *airports with substitution of indirect flights* (London, Amsterdam, Madrid, Frankfurt, Vienna, Rome, Nice, Geneva, Barcelona); (b) *airports with increase in the number of direct flights* (Paris, Brussels, Copenhagen, Zurich); (c) *airports with increase both in direct and indirect flights* (Manchester, Munich, Stockholm, Oslo, Dusseldorf, Hanover); and (d) *airports with positive values for Mohring effects* (Athens, Lisbon, Birmingham, Dublin, Helsinki). The main conclusion of the analysis of results by airports is that the later group of airports –all located at the periphery of Europe– have experienced time losses in the process of re-configuration of airlines' networks.

- A final exercise with the obtained results for t_i and t_{as} is the econometric estimation of marginal Mohring effects. A non-linear relationship between the level of demand and total time spent by each passenger ($t=t_i + t_{as}$) is found. This implies that Mohring effects are less important the denser a route becomes. For a route density of 25,000 pax per year, the entry of 10,000 additional passengers generates a net gain of 56 minutes (€ 14.51 per pax). When the initial density is 50,000 passengers/year, the Mohring effect of the same entry of new travelers goes down to 16 minutes (€ 4.15), and for a density of 150,000 passengers/year, it is evaluated in 2 minutes (€ 0.52).

1. Objectives of the case study

The European air market completed its process of de-regulation in 1997. After that date, any airline from a EU Member State may operate in any intra-EU route regardless of its nationality. This has been an enormous change for the European air industry, which before the 1990s operated under a heavy regulation about what companies could serve a route, what level of service should be provided, and what fares charged to passengers.

Although before deregulation airlines had to take demand levels into consideration when designing their networks, the companies enjoyed a quiet life during the period of regulation. Passengers had to adapt to the conditions of supply (flights offered and scheduled times, and regulated fares), with few alternative options. The situation has now been altered so that now airlines have to adapt their business plans to the existent demand conditions. Competition among carriers, and the threat of entry of new rivals in a route, force companies to schedule optimally their flights in order to retain or capture market shares.

In a deregulated fully competitive market, each airline will choose a network configuration (cities to serve, routes, flight schedules and types of aircraft) to maximise its profits. Thus market forces will lead supply conditions to reflect passengers' preferred flying times, and types of services (first-class, business, tourist). It is obvious that real air markets are not perfectly competitive and that there exist some rigidities that airlines face when designing their networks. Saturated airports and acquired 'grandfather' rights over landing slots are probably the most relevant constraints in Europe at present for airlines' decisions. But, nevertheless, after deregulation, airlines have much more freedom to design their networks and to choose what level of supply to provide.

It is in this context of level and quality of supply of air services being largely determined by demand, where it is possible to discuss and evaluate the existence of the so-called 'Mohring effect' for air transport. In a seminal paper related to the bus industry, Mohring (1972) presents the idea about how an increase in the frequency of service in a bus route, induced by a change in demand, improves the welfare of all travellers using buses in that route. The idea is that the increase in the frequency of buses perhaps does not alter the volume of service per passenger (e.g. when a company doubles the number of buses because demand has doubled, each bus will be carrying the same number of passengers), but it will reduce the waiting time of passengers at stops. Thus, each additional traveller deciding to use a bus generates a positive externality on others, by inducing changes in the level of service.

For air transport, departure times of planes are not so severely affected by traffic conditions as in the case of buses (although airport congestion also generates delays for this mode of transport[1]). Therefore, Mohring effects do not stem here from random arrival of flights to airports. However, there are also positive externalities that changes in demand generate for all passengers using a route. Decisions taken by airlines, regarding the configuration of their

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[1] Within the UNITE project, there is another work analyzing congestion problems in air transport (case study 7i, congestion at Madrid airport). This case study illustrates how the assumption of travellers knowing flight departure times without uncertainty is presently not very realistic in Europe, and in fact there are many negative externalities generated by saturation of airports. However, the presence of congestion effects does not invalidate the existence of Mohring effects for air transport discussed in this work.

networks and flight schedules, clearly may have a direct impact on air travellers, in terms of time consumed by them in the activity of transport.

The main objectives pursued in this work are the following:

- Discuss the applicability of the concept of Mohring effects for air transport
- Evaluate empirically the importance of these effects for the European air market
- Provide a methodological approach which can be transferred to the context of other transport modes with scheduled services.

A sample of routes between European airports provides data on flight schedules, which has been exploited to evaluate the existence of positive externalities. The change in supply conditions between 1990 and 1998 is the context in which Mohring effects are calculated. Ideally, it would be interesting to examine what has been the impact of deregulation on the supply of air services (entry of new companies, changes in level of existent services, and so forth), for which it is necessary to allow a sufficiently long period of time for market forces to operate. Unfortunately, data availability limits the analysis to 1998 as the latest year, which is a date relatively close to the completion of the deregulation process. Nevertheless, the period chosen for the analysis is sufficiently long (eight years) for market conditions to have been substantially modified so as to allow the possibility of measuring benefits for passengers induced by changes in demand.

The work is structured as follows: section 2 briefly revises the concept of Mohring effects for the bus industry and its application to the air industry, and presents a simple model to provide the framework to discuss the evaluation of positive externalities for air passengers. Section 3 describes the methodology used in the empirical calculation of times involved for passengers. Section 4 presents the data and some descriptive statistics about intra-European routes. Section 5 is devoted to the quantification of Mohring effects and their analysis, and contains the main results. Transferability of these results to other contexts and transport modes is discussed in Section 6. Finally, Section 7 summarises the main results.

2. Mohring effects in transport

Mohring (1972) emphasizes the role of transport users not only as consumer of services, but also as producers of these services. When using any transport mode, travellers and shippers have to provide their own time –or that of the good they ship– in order to consume transport services. This time can be considered as an additional input to the transportation activity. Then, the full cost of transport services will not only include fares, but also the monetary value of time spent in the trip. Following De Rus (1997), let us assume that the total cost per hour (*TC*) that a bus operator incurs into for a given route is:

$$TC = wN \tag{1}$$

where w is a cost per bus-hour, and N is number of buses in service. Consider that the average cost per passenger for the producer is constant (this assumption is consistent with the empirical finding of CRS usually obtained in studies on the bus industry). If demand is represented by q, then the average cost will be given by the following expression:

$$AC = \frac{wN}{q} = c \tag{2}$$

From a bus user' perspective, the generalized cost will be given by:

$$GC = p + c_u = p + t_a v_a + t_w v_w + t_i v_i \tag{3}$$

where p is the fare, t_a is the access time required to go from home/work to the bus stop and from the bus stop to final destination, t_w is the waiting time at the stop and t_i is the travel time in the bus. The corresponding monetary values for these times are v_a, v_w and v_i, respectively. Finally, c_u represents the value that the traveller attaches to the time required by the transport activity, and is formed of the three components indicated in the expression.

The social cost will then be:

$$SC = wN + c_u q \tag{4}$$

Let us assume now that, for some reason, the demand for bus services doubles so that the number of passengers wishing to travel rises to $2q$. If the bus company responds by duplicating N, in that case its total and average costs become:

$$\textit{Total cost:} \quad TC = 2wN \tag{5}$$

$$\textit{Average cost:} \quad AC = \frac{2wN}{2q} = c \tag{6}$$

In addition, if one assumes that passengers will arrive to the bus stop randomly, the increase in the number of servicing buses will result in a reduction of t_w , and necessarily in a reduction of c_u. As a consequence, the cost for the user reduces by $dc_u/dq < 0$, whilst the average costs for the bus operator remains constant. It is then observed that the increase in supply results in a net social gain.

In summary, the Mohring effect refers to these reductions on users' cost. As a result of the increase in number of buses (frequency), the costs for the user decreases, even in the case that the carrier experiences constant returns to scale. It is important to note that in the case of buses, the reduction in c_u arises from a reduction in t_w, i.e. the time the passenger has to wait at the stop for a bus to come. Neither the access nor the travel time will change after the change in frequency given Mohring's assumption regarding constancy in the number of bus stops.

2.1 The Mohring effect in air transport

As we have seen above, the Mohring effect was originally discussed in the context of the bus industry (Mohring, 1972), and it has not been generally extended to other transport modes.

For buses, the Mohring effect relates to the reduction of waiting times at bus stops. Even if in other transport modes the arrival of vehicles to pick passengers does not share the stochastic nature of buses, which are affected by changing road and traffic conditions, there might exist effects of similar nature. Variations in demand that induce changes in supply conditions are likely to generate some positive externality effects for transport users.

For air transport, the type of Mohring effect just discussed for the bus industry is not directly applicable. When a passenger decides to fly and buys a ticket, she knows in advance which will be the flight she will be boarding, with all relevant details as departure and arrival scheduled times[2]. However, changes in the frequency of flight services on a route might have a direct impact on passengers in terms of time spent in the activity of transport. The relevant times for air passengers in the consumption of services are three:

(i) *Access time (t_a).* Time spent by passengers from home/office to the airport, including the waiting time at the airport (known in advance, in absence of delays), until the moment of departure. No changes in access times to the airport are expected after modifications of flight frequencies. A second component of access time would be time spent from the arrival airport to final destination.

(ii) *'Adjustment-to-schedule' time (t_{as}).* This is the gap between the preferred departure time that the passenger would have chosen, and the actual flight departure time that is forced to choose (Hsu and Wu, 1997; Teodorovic, 1988; Swan, 1979).

There are two components related to this time. The first one is generated by the scheduled offered by companies, i.e. a passenger only may leave a city not when she wants, but when there is a programmed flight. The second one is an stochastic component: even if a passenger has opted for a flight as her best first option, the flight could be completely booked. In that situation, there would be some additional time associated to the gap between the preferred departure time and the second-best option.

(iii) *Travel time (t_i).* This is the total time spent in the journey, between the moment of departure to the moment of arrival. For direct flights, this is simply time inside the plane, but for those flights involving connections, it will also add the hours spent at intermediate stops (waiting time for connecting flights, and extra time for additional take-offs and landings).

When air carriers alter their frequencies as a response to changes in demand conditions, passengers' generalised cost will vary mainly for two reasons:

1. Travel times (t_i) might change as a result of the new mix of direct/indirect flights.
2. Passengers are forced to adapt their preferences to the new flight schedules, so the values for t_{as} may change.

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[2] There is only one exception to this form of organisation for air transport and these are the so-called 'air-shuttles'. For some dense routes, services are operated on a first-come/first-served basis, so passengers face some uncertainty about the possibility of not being able to board the next available flight if completely sold. But, apart from this exception, which is not frequent in the context of European routes, air travellers have all basic information regarding the transport service that they will use.

The first one (impact over t_i) would be generated by the network configuration of a carrier. The trend observed in the US industry towards 'hub-and-spoke' configurations has generated more flight availability to passengers, but at the same time has increased in general the amount of travel time (by substituting direct flights with indirect connections through hub airports). Therefore, when a company responds to demand by offering a given number of direct and indirect flights to serve a route is imposing on them some value for their average travel time t_i.

The second type of Mohring effect is reflected in the idea of 'adjustment-to-schedule time' (t_{as}). As described, this is the cost borne by travellers due to the inconvenience of having to adapt their preferences to the existent schedules offered by airlines. When a company modifies its schedule, it introduces changes in these adjustment times. Some passengers may benefit from the fact that a new flight is placed closer to their preferred departure times, while others can be harmed by the elimination of flights. In general, it can be expected that the introduction of more flights in a route results in lower adjustment times, which is the benefit that new travellers generate for other passengers.

Due to data availability, it is almost impossible to try to evaluate the stochastic part of the 'adjustment-to-schedule' time, because that would involve to have information about how frequent is that a passenger finds that its preferred flight is fully booked. Thus, for the empirical part of this work, we focus on the first non-random component of 'adjustment-to schedule' times, and compute them under some assumptions which are detailed below.

Hence, the total Mohring effect in air transport may be interpreted as the resulting changes in travel times (t_i) and adjustment-to-schedule times (t_{as}), after a change in airlines' flight schedules.

In this case equation (3) becomes, for the case of air transport:

$$GC = p + c_u = p + t_a v_a + t_{as} v_{as} + t_i v_i \tag{7}$$

Taking two dates 1 and 2 as a reference, changes in the generalized cost for passengers $DGC = GC_2 - GC_1$ will be (assuming that fares between the two periods remain constant):

$$DGC = D\,t_{as} v_{as} + D\,t_i\,v_i \tag{8}$$

While in the Mohring (1972) analysis of buses it is clear that an increase in frequency leads to a reduction in waiting times, in air transport it is not straightforward to predict what the consequences of a change in the number and type of flights (direct/indirect) will be. The reason is that for the air industry an increase in frequencies might be done through an increase of indirect connections, which might induce longer travel times.

Therefore, it is an empirical question to evaluate how changes in airlines' schedules alter t_i and t_{as}, and the net impact caused on passengers. The evaluation of Dt_i and Dt_{as} to be used in expression (8) is the main objective of this work.

3. Methodology

The methodology applied in this work is to evaluate changes in travel times (Δt_i) and adjustment-to-schedule times (Δt_{as}), resulting from variations observed in European airlines' schedules between 1990 and 1998. For this purpose, a sample of 469 intra-European routes connecting the main European airports, which is described in detail in the next section, has been used.

3.1 Estimation of changes in travel times (Δt_i)

Travel times are calculated for each route as a weighted average including all flights (direct and indirect) operated in the route. Calculations are performed by considering all weekly flights available between the two endpoints, and obtaining the average travel time for a representative passenger picked randomly.

Time t_i is calculated as the difference between the programmed departure time and the arrival time at final destination. Thus, for direct flights t_i represents time 'in-the-plane', while for indirect flights (connecting at an intermediate stop), it is time 'in-the-journey', including all those times that passengers spend in the planes plus time at connecting airports.

For each route, the basic result is the difference between the value obtained for t_i in 1990 and 1998, i.e. $\Delta t_i = t_{i98} - t_{i90}$. This figure will indicate if passengers are being forced to spend more or less time in the journey by changes introduced by airlines in their networks' configuration. A positive value for Δt_i implies then that travellers on a given route must use more connecting flights, which generate longer average travelling times.

Although this is the main explanation for a positive sign for Δt_i, it can also be the case that the number of direct and indirect flights is the same between 1990 and 1998, but indirect flights make connections through different routings, which could take longer times. Another caveat is that direct flights may have slight differences according to the type of aircraft used. Airlines may assign travel times for direct flights that can oscillate for some routes by more than 30 minutes in some cases (longer routes have more variability).

An example with data on a particular route will help to illustrate the type of exercise performed to evaluate changes in t_i. Consider the following real case:

City of origin: Amsterdam; City of destination: Athens; Distance: 2,174 km

Flight availability in a summer week of 1990:

17 direct flights, average travel time: 3.26 h

42 indirect flights (connecting via Frankfurt, Rome, Brussels, Zurich or Sofia). Average travel time: 5.96 h

Total average travel time: 5.18 h

Flight availability in a summer week of 1998:

25 direct flights, average travel time: 3.58 h

7 indirect flights (connecting via Budapest or Sofia). Average travel time: 5.25 h

Total average travel time: 3.95 h

Change in travel time: Δt_i = - 1.23 h

Thus, for this route it is obtained a negative value for Δt_i , which indicates that an average passenger in the route Amsterdam-Athens is better off in 1998 than in 1990 in terms of time spent in the journey between these two cities. While in 1990 a passenger had to spend 5h 11min to reach Athens from the moment she departed from Amsterdam, in 1998 this time is on average 3h 57min.

However, this figure only indicates benefits (losses) for the first type of Mohring effect discussed. Clearly, it has to be complemented with the information about how the change in supply –and specially in the schedule of departures– affects passengers. In the particular route of this example, the number of total flights has been greatly reduced although the number of direct flights increases, therefore it is not immediately obvious what is the total effect caused on travellers.

3.2 Estimation of changes in adjustment-to-schedule times (Δt_{as})

The evaluation of the second type of Mohring effect on passengers requires the use of some assumptions on the preferences of passengers for departure times. It is quite difficult to design a model which could be considered as perfectly representative for all routes included in the sample (due to differences in length, density, and type of travellers). Business travellers will generally have a preference for flights departing early morning and early evening, but those preferences probably vary according to the journey's length (someone attending a meeting at 8:00 am will probably prefer late evening departures on the previous day, if the travelling time is above 2 hours). Meanwhile, leisure passengers would like to avoid early and late departing hours, but might opt for those flights if fare differences between them and more convenient departing times are substantial.

Due to lack of information about numbers of each type of travellers, and fares charged by airlines for each flight in the route, the exercise performed in this case study necessarily needs to rely on a number of simplifying assumptions. The model proposed for the evaluation of 'adjustment times' (=difference between the preferred departure time and the actual schedule offered by companies) has the following features:

- Passengers want to use departures between 6:00 am and 22:00 pm
- Preferences are uniformly distributed over that interval of times (the number of passengers wishing to depart at each hour is constant).
- In order to pick the best available flight according to her preferences, each passenger takes as a reference one particular rounded hour (e.g. 6:00am, 7:00am, 8:00am and so forth). Thus, it is possible to normalise all routes by representing them as 17

passengers –one for each rounded hour between 6:00 and 22:00– uniformly distributed. As we work with weekly data, this scheme is equivalent to evaluate the decision of 119 passengers (17 × 7 days) with respect to what flight to choose.

- The flight chosen by each passenger is the one closer to her corresponding hour of reference, based on the real weekly schedules offered by all airlines operating in the route.

- The final result for each rout is an average value for t_{as}, considering all values calculated for the 119 weekly passengers using the route.

An example may help to understand the methodology used to calculate t_{as}. Let us consider again the route Amsterdam-Athens to evaluate t_{as} according to the available flights scheduled for a Monday in 1990 and 1998 (the same type of analysis will be performed for the rest of days from Tuesday to Sunday, with their corresponding schedules).

<u>Route</u>: Amsterdam-Athens

(A) Monday 1990: Available flights (? = direct flight; ? = indirect flight)

```
6    7    8    9   10   11     12   13   14   15    16   17    18   19    20   21  22
+ - - + - ? + - ? + - ? + - - + - ? + - ? + - ? + - ? + - - + - ? + - - + - - + - - + - - + - - ¦
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Departures *7:15* *8:50* *9:35* ***11:35*** ***12:40*** *13:20* *14:20* *16:35*

Evaluation of adjustment times between preferred times and scheduled flights

Passenger's preferred departure time	Adjustment time (hours)	Passenger's preferred departure time	Adjustment time (hours)
6:00	7.25 – 6 = 1.25	15:00	15 – 14.33 = 0.66
7:00	7.25 – 7 = 0.25	16:00	16.35 – 16 = 0.35
8:00	8 – 7.25 = 0.75	17:00	17 – 16.35 = 0.65
9:00	9 – 8.83 = 0.17	18:00	18 – 16.35 = 1.65
10:00	10 – 9.58 = 0.42	19:00	19 – 16.35 = 2.65
11:00	11.58 – 11 = 0.58	20:00	20 – 16.35 = 3.65
12:00	12 – 11.58 = 0.42	21:00	21 – 16.35 = 4.65
13:00	13 – 12.67 = 0.33	22:00	22 – 16.35 = 5.65
14:00	14.33 – 14 = 0.33		

Total adjustment time for Monday-90 (adding all 17 passengers): 24.41 h

Adjustment time per passenger (average): **1.44 h.**

(B) Monday 1998: Available flights (? = direct flight; ? = indirect flight)

```
            6     7     8     9     10    11    12    13    14     15    16    17   18    19      20    21  22
            + - - + - - + - - + - ?  + - ? + - - + - ? + - - + - ? + - - + - - + - - + - - + - ? - + - ? + - - ¦

Departures                          9:45  10:10      12:40      14:40                            19:25  20:15
```

Evaluation of adjustment times between preferred times and scheduled flights

Passenger's preferred departure time	Adjustment time (hours)	Passenger's preferred departure time	Adjustment time (hours)
6:00	9.75 – 6 = 3.75	15:00	15 – 14.67 = 0.33
7:00	9.75 – 7 = 2.75	16:00	16 – 14.67 = 1.33
8:00	9.75 – 8 = 1.75	17:00	17 – 14.67 = 2.33
9:00	9.75 – 9 = 0.75	18:00	19.42 – 18 = 1.42
10:00	10 – 9.75 = 0.25	19:00	19.42 – 19 = 0.42
11:00	11 – 10.17 = 0.83	20:00	20 – 19.42 = 0.58
12:00	12.67 – 12 = 0.67	21:00	21 – 20.25 = 0.75
13:00	13 – 12.67 = 0.33	22:00	22 – 20.25 = 1.75
14:00	14.67 – 14 = 0.67		

Total adjustment time for Monday-98 (adding all 17 passengers): 20.66 h

Time per passenger: **1.22 h.**

The conclusion derived from this example is that a representative passenger flying on a Monday from Amsterdam to Athens has benefited by a reduction of 0.22 hours on her adjustment time between preferences and actual scheduled departures. This is the result of a combination of factors:

- An increase in the number of direct flights (from 2 to 4)
- A reduction in total number of flights (from 8 to 6)
- A wider spread in the range of departures (last flight in 1990 at 16:35; in 1998 last connecting flight departing at 20:15)

The combination of all these factors shows that passengers flying from Amsterdam to Athens are better off in that particular day of the week. When the exercise is performed for the rest of days of the week for this particular route, the result is reinforced:

- Total weekly adjustment time 1990: 205.8 h.
- Total weekly adjustment time 1998: 162.8 h
- Change in average weekly adjustment time per passenger: $\mathrm{D}\mathbf{t}_{\mathbf{as}} = -\,\mathbf{0.36}$ **h**

3.3 Total Mohring effect

In order to evaluate the total Mohring effect, the two type of impacts evaluated –changes in travel-times (t_i) generated by changes in route networks, and changes in adjustment-to-schedule-times (t_{as}) generated by modifications in flight departure schedules– must be added.

Total Mohring effect per passenger = $Dt_i + Dt_{as} = (t_{i98} - t_{i90}) + (t_{as98} - t_{as90})$

- Negative values indicate time savings
- Positive values are time losses

In the former example Amsterdam-Athens, total time savings are then equal to:

$$Dt_i + Dt_{as} = (-1.23) + (-0.36) = -1.59 \text{ hours}$$

Ideally, one would like to refer this time saving per passenger to the level of demand, which had induced airlines to alter their schedules. However, there are several difficulties to perform that exercise, due to the available information. First, passengers statistics compiled by International Civil Aviation Organization (ICAO) refer only to direct flights. Travellers using indirect connections are then reflected separately in the flight stages used in their trips. Second, the quality of data on passengers is not extremely satisfactory, so a filtering process is required before relating time savings (losses) to changes in demand.

The main results of this work are then presented as average time savings per passenger for each route. These data can be considered of good quality, based on the assumptions used. Additionally, marginal time savings induced by the entry of additional passengers are also provided. These are calculated with a reduced number of routes, for which data on passengers have been checked, and can also be regarded as of acceptable quality. Finally, total time savings for the whole sample analized in this work are also calculated, to assess the relevance of Mohring effects for air transport. Figures on total savings, however, must be interpreted only as a proxy of real gains attributable to Mohring effects, because of the limitations described on the information on route densities.

Another issue is the translation into monetary values of time savings obtained in this work. The valuation of time for air transport is complicated in this context, due to several reasons: (i) the international nature of the sample of routes; (ii) the different nationalities of passengers using flights; and (iii) the different travel purposes (business, leisure), for which there are no detailed statistics.

In order to find a solution for all these issues, the option has been to apply UNITE valuation conventions for travel times, using average European values for all routes, i.e. without correcting for national differences on income. Standard values are 28.5 €/hour for business travellers, and 10 €/hour for leisure travellers. Based on the assumption of business passengers representing 30% of total demand, this results in an average value of **15.55 €/hour** which is used throuhgt the work to evaluate time savings (losses) in monetary terms.

4. Data

A group of 26 European airports was selected for the empirical analysis of Mohring effects. The criterion followed for the sample selection was to have at least one airport for each EU Member State, plus Norway and Switzerland. The main airport for each country is included in the sample, and for some countries (France, Germany, Italy, Spain, Switzerland and UK) several airports are included. **Table 1** shows the list of all airports and a detailed description of routes can be found in Annex 1.

Table 1: Airports included in the sample

Country	Airports	Country	Airports
Austria	Vienna	Luxembourg	Luxembourg
Belgium	Brussels	Netherlands	Amsterdam
Denmark	Copenhagen	Norway	Oslo
France	Paris, Nice	Portugal	Lisbon
Finland	Helsinki	Spain	Madrid, Barcelona
Germany	Frankfurt, Dusseldorf Munich, Hanover	Sweden	Stockholm
Greece	Athens	Switzerland	Zurich, Geneva
Ireland	Dublin	UK	London, Manchester Birmingham
Italy	Rome, Milan		

From the 650 potential origin/destination pairs that could be in principle formed with the selected airports, 469 routes were finally chosen for the analysis. Some of the potential o/d pairs do not have in practice any direct or indirect service[3] so they could not be included, while others presented problems to obtain the required information. Nevertheless, the sample is considered to be highly representative of total international intra-European air traffic.

Figure 1 presents a map showing all airports in the sample and a selection of densest routes with more than 250.000 passengers (one way) in 1998. **Table 2** shows some basic statistics of the routes considered for the analysis.

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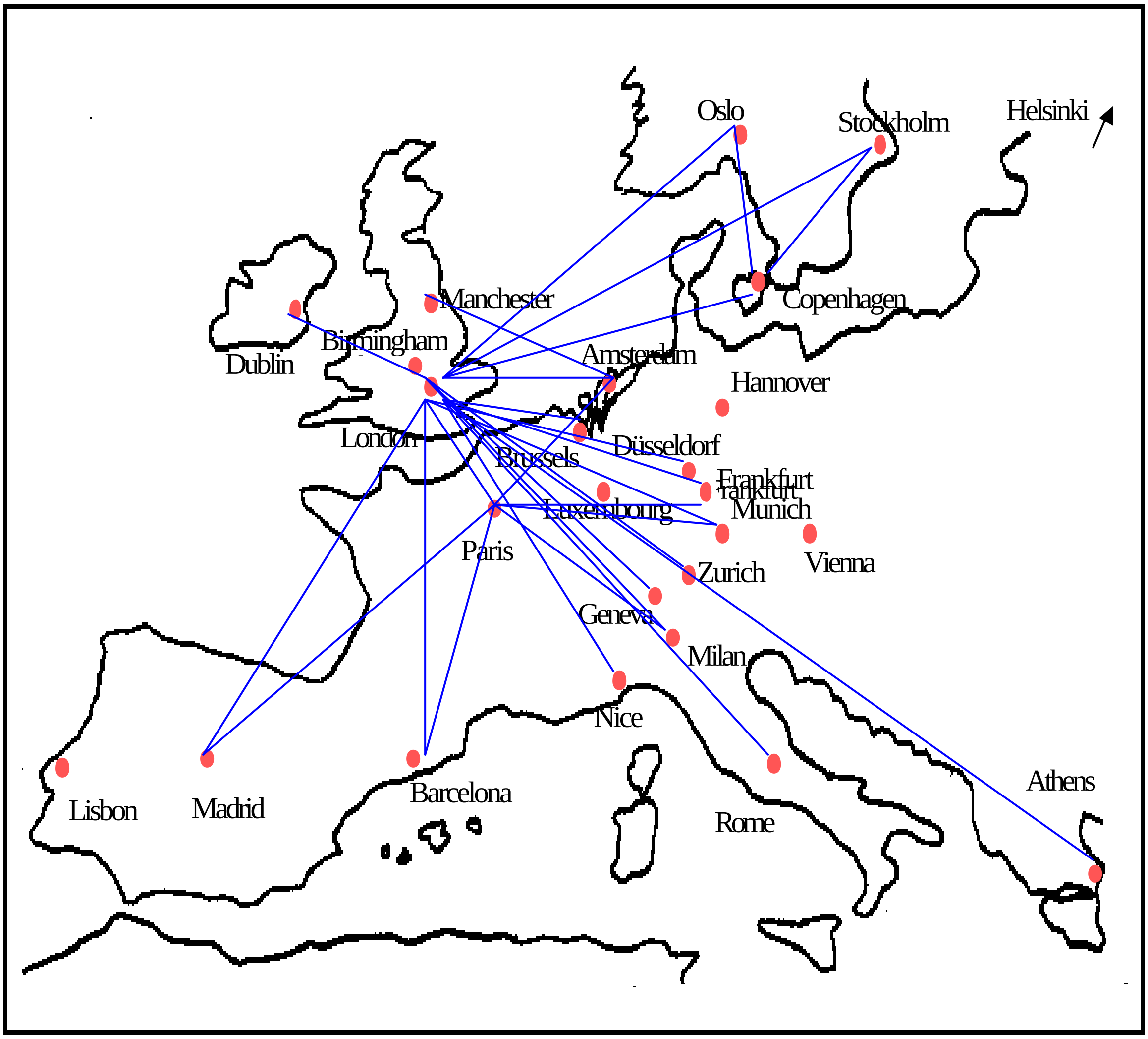
[3] Indirect services are defined as those offered by a single airline or group of airlines, which involve the realisation of a journey through several stages. These stages are co-ordinated to minimise time at stops, and are sold as a single ticket to the passenger. The non-existence of service means that no indirect connections as defined are available in the market, although a passenger may travel from any European city to another using several combinations of routes and companies.

Figure 1. Sample of European airports



Note: only the densest routes (more than 250,000 pax per year) included in the sample are represented in the figure

Table 2. Description of routes in the sample

Number of routes	469	
Total number of passengers (1998) *	51.23 mill.	
		Standard dev.
Average route length	1,170 km	(645.3)
Average route density (1998)	157,621 pax.	(198,103)
Average weekly direct flights (1998)	43.9	(57.2)
Average weekly indirect flights (1998)	22.6	(27.0)

* *Note*: Only 325 routes (69% of sample) reported passengers' figures, so the sample represents a larger number of intra-European passengers

Collected data refers to flight schedules for direct and indirect flights (programmed departure and arrival times, plus connecting times), and some route characteristics (length, number of passengers). Data on frequencies were obtained from the *OAG World Airline Guides*, a monthly publication with detailed information on flight schedules. The information used corresponds to the months of May 1990 and May 1998. The second type of data corresponds to route length and passenger density, obtained form the publication *Traffic by Flight Stage* (ICAO).

4.1 Descriptive analysis of routes

Some descriptive statistics provide an idea of the sample used for this study. As **Table 2** shows, the average length of intra-European routes is 1,170 km, and around 160,000 passengers per year use air transport services on a representative route. Overall, the sample represents total movements of 51.2 million passengers in 1998. It must be remarked again that data on passengers is not available for all routes in the sample, and that figures on passengers refer only to direct flights. As the ICAO publication *Traffic by Flight Stage* refers only to international routes, all domestic corridors in our sample (combinations between airports from the same country) do not have data on traffic.

Behind these average figures, there is a wide variability of routes. **Table 3** presents some results by route length and density, which reveal some interesting features. Regarding route length, more than half of European routes is in the range of 500-1,500 km (58.2%), but there are significant proportions of shorter routes (17.1% with less than 500 km), and long ones (11.1% with more than 2,000 km). The shortest routes are Amsterdam-Brussels (157 km) and Amsterdam-Dusseldorf (178 km), while the longest are Helsinki-Lisbon (3,364 km) and Helsinki-Madrid (2,947 km).

Route densities fall when origins and destination are more distant. Those routes with length below 500 km have more than 300,000 pax per year on average, while routes above 2,000 km only carry around 55,000 pax, i.e. almost six times less. Correspondingly, the number of weekly flights differs notably between these two groups (102.2 flights for short-haul routes vs. 32.7 flights for long-haul ones), and so does the flight-mix of direct and indirect connections.

According to route density, around half of the routes for which there is available information on passengers is below 100,000 passengers per year, with a total number of 48.3 weekly flights. This corresponds roughly to 7 flights per day, which indicates that the level of service is quite good even for the less dense routes.

Meanwhile, there is a relatively small fraction of routes which are much denser than the average. Around 15% of routes carry more than 250,000 per year (those represented in **Figure 1**), and there are 14 routes with more than half-million passengers in 1998. This group of routes is served mainly by direct flights –although some of them have also indirect connections– and the average number of weekly flights is 215, i.e. around 30 daily services. The corridors Amsterdam-London and London-Paris include the four densest routes in Europe, with more than one million passengers per year each way.

Table 3. Distribution of routes by length and density

	Number of routes		Average density (pax 1998)	Number of weekly flights		
				Direct	**Indirect**	**Total**
< 500 km	80	17.1%	309,002	94.9	7.3	102.2
501-1,000 km	134	28.6%	151,413	51.2	20.4	71.7
1,001-1,500 km	139	29.6%	147,473	33.8	28.1	61.9
1,501-2,000 km	64	13.6%	75,542	15.2	33.6	48.8
> 2,000 km	52	11.1%	54,823	8.7	24.0	32.7
			Av. length (km)			
< 100.000 pax	165	50.8%	1,273	22.3	26.0	48.3
100-250.000 pax	109	33.5%	949	54.1	20.4	74.5
250-500.000 pax	37	11.4%	921	110.1	28.5	138.6
> 500.000 pax	14	4.3%	640	208.3	6.8	215.1

5. Quantification of Mohring effects

As a preliminary step before computing Mohring effects, it is interesting to study changes in supply conditions between 1990 and 1998. The global picture is one of an increase in the average number of weekly flights, which can be established around a 27% for total flights (from 52.3 flights on average per route in 1990 to 66.5 in 1998). This larger supply of flights is basically formed of direct connections, which increase from 28.6 to 43.9 (53%), while indirect flights have experienced a relatively small reduction, from 23.6 to 22.6 (-4%).

Behind the average figures, the evolution of supply conditions has been quite heterogeneous across Europe. Even though the general picture is one of increase in the number of flights, with more direct flights between the main European airports, a detailed analysis shows that for some routes total supply has decreased. For other routes, the combination of direct/indirect flights has been altered in the opposite direction to that of the general trend (more indirect connections, and reduction in total number of flights).

Based on changes in the number of direct and indirect flights between 1990 and 1998, the routes in the sample can be classified into several groups. These groups are the following (see **Table 4**):

(i) Groups 1, 2 and 3 correspond to routes where supply has decreased between the two years of reference, either by a reduction in the number of direct flights, indirect flights, or both. Taken together, they represent 13.9% of routes in the sample. The main conclusion for those groups is that for a relatively important fraction of passengers, supply conditions in 1998 are worse than in 1990. The average length for routes in these groups is relatively large, so the interpretation is that long and low-dense routes are the ones that have experienced reductions in the number of flights.

Table 4. Groups of European routes according to changes in supply conditions

Group	DDF	DIF	Number of routes		Average length (kms)	Average density (thous.pax 1998)
1	–	–	35	7.5%	1,792	23.2
2	–	**0**	11	2.3 %	601	287.2
3	**0**	–	19	4.1 %	1,528	100.0
4	+	–	155	33.1 %	1,129	161.5
5	–	+	32	6.8 %	1,584	42.4
6	**0**	+	25	5.3 %	1,235	41.3
7	**0**	**0**	2	0.4 %	822	15.0
8	+	**0**	71	15.1 %	651	227.2
9	+	+	119	25.4 %	1,119	132.2
Total			*469*	*100.0 %*	*1,128*	*145.2*

DDF = Change of direct flights

DIF = Change of indirect flights

(ii) Group 4 includes a number of routes where more direct flights have been introduced, while decreasing at the same time the number of indirect flights. In these routes, passengers are presumably much better in 1998, although the reduction of indirect flights must be carefully studied (a large reduction of IF may imply longer adjustment times if the number of DF does not compensate passengers).

(iii) Groups 5 and 6 exhibit a pattern of changes that can be named as a trend towards 'hub-and-spoke' configurations. Passengers suffer from a reduction in the number of direct flights (group 5), but on the other hand they are offered more connecting flights. The total impact on their welfare is then ambiguous, because they are forced to have longer travel times t_i but might have shorter adjustment times t_{as}. Together, these two groups represent a 12.1% of the sample. Results obtained for this group of routes can be used to assess the importance of hub-and-spoke network configurations in Europe. Groups 5 and 6 represent relatively lengthy routes with low density (around 40,000 pax per year, which is equivalent to one fourth of the global average).

(iv) Finally, routes in groups 8 and 9 have a larger supply of flights in 1998 compared to 1990, so passengers flying in those routes will be generally better off. Mohring effects can consequently be expected to show up as negative values for Dt_i and Dt_{as}. (time savings for travellers). These two groups represent 40.5% of the sample, therefore a majority of intra-European routes have experienced an increase in flight availability between 1990 and 1998.

5.1 Evaluation of total Mohring effects

Based on the methodology described above, for each route the travel time t_i and the adjustment-to-shedule time t_{as} have been calculated for 1990 and 1998.

For the whole sample, average values obtained for the differences in time for both magnitudes are the following:

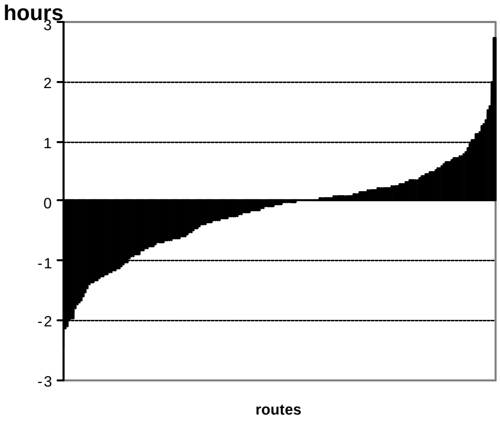
- Change in travel time: Dt_i **= - 0.19 hours** (-11.4 minutes)
- Change in adjustment-to-schedule time: Dt_{as} **= -0.15 hours** (-9 minutes)

Therefore, an average European traveller using flights on intra-EU routes had in 1998 a total time saving of 20 minutes, compared to the situation in 1990. This is the empirical evaluation of the positive externality generated by changes in demand for air transport between the two periods.

Even though time savings per passenger coult appear as not extremely important, total time saved by all passengers represented in the sample of routes chosen is quite large, amounting to 20.94 million hours. Translated into monetary terms, according to UNITE valuation conventions, these time savings would represent a total of € 325.6 million

Figures 2 and 3 show the distribution of Dt_i and Dt_{as} across the sample of routes, to have a general picture about how many routes have improved their situation between 1990 and 1998. Complete results for Dt_i and Dt_{as} for every route can be found in Annexes 2 and 3, respectively.

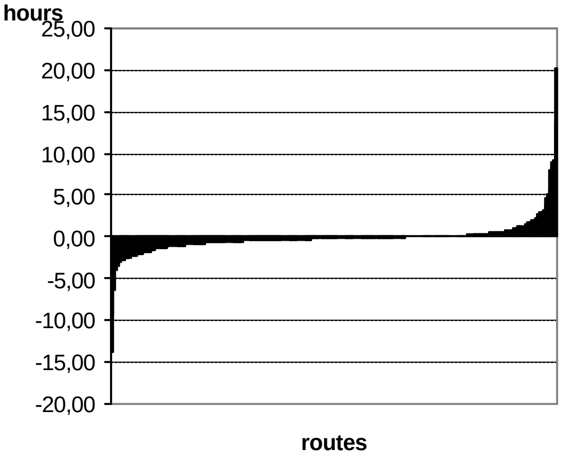
Figure 2. Values of Dt_i for all routes in the sample*



*Ordered by the amount of time saved or lost

Figure 2 shows how more than half of the routes in the sample exhibit negative values for t_i, thus indicating that air travellers have benefited from changes in supply conditions, through a reduction in travel times. For 15% of routes, the gain per passenger is above one hour. Meanwhile, in the group of routes for which conditions are worse in 1998 than in 1990, there is also some fraction of routes which have relatively large losses. Taking again the reference of one hour, 5% of routes in the whole sample exhibit values for Dt_i larger than one.

Figure 3. Values of Dt_{as} for all routes in the sample*



*Ordered by the amount of time saved or lost

The magnitude of effects associated to changes in adjustment-to-schedule times t_{as} is much larger in general than those of travel time t_i. (Observe that the range of variation in the Y-axis of figures 2 and 3 is different). In this case, more routes present negative values for parameter Dt_{as} than in the previous figure, therefore it is concluded that the benefits in adjustment-to-schedule times are more relevant than those of travel times.

Some extreme cases are observed, with gains per passenger above five hours, and at the other end of the distribution, losses above ten hours. These observations correspond to routes with little levels of service, where the introduction or withdraw of flights may have a dramatic impact on adjustment times imposed on passengers.

5.2 Analysis of Mohring effects by type of routes

With the values obtained for Dt_i and Dt_{as}, it is possible to characterise the average impact caused by changes in supply conditions, for each of the nine groups of routes described above (see **Table 5**)

As already mentioned, a representative traveller flying within Europe in 1998 had a net gain of 0.34 hours, derived from demand increases from other passengers. However, the situation varies when one analyses the changes for particular groups of routes. For some of them, the opposite result is obtained , and passengers are worse off in 1998 compared with the situation in 1990.

In particular, travellers on routes included in groups 1-3 have positive results for total Mohring effect, though some of them had a reduction in travel times (negative values for Dt_i). Passengers in groups 1 and 3 spent in 1998 one hour and thirty minutes and three hours more, respectively, than in 1990. Passengers in group 2 had about the same times in 1990 and 1998.

Passengers using routes included in the other groups of routes have generally benefitted from changes in the flight schedules between 1990 and 1998, specially for groups 4, 6, 8 and 9, with average time savings close to one hour per passenger for all of them.

Table 5. Results by groups of routes

	Route group	**Percentage over total sample**	Dt_i* **(hours)**	Dt_{as}* **(hours)**	***Total Mohring effect per passenger* (hours)***
Reduction of supply	1	13.9%	-0.24	1.78	1.54
	2		0.07	-0.03	0.04
	3		-0.57	3.59	3.01
Substitution IF by DF	4	33.1%	-0.78	0.06	-0.72
Hub-and-spoke	5	12.1%	0.41	-0.55	-0.15
	6		0.30	-1.21	-0.91
	7	0.4%	0.09	-0.17	-0.08
Increased supply	8	40.5%	0.04	-0.76	-0.72
	9		0.24	-0.91	-0.67
	Total sample	**100%**	**-0.19**	**-0.15**	**-0.34**

* Simple averages over routes in each group (not weighted by route densities)

5.3 Analysis of Mohring effects by airport of origin

This section evaluates the impact of changes in flight availability over passengers departing from each airport included in the sample[4]. **Table 6** summarises the obtained results. For each airport, it is indicated the number of routes departing from it, and the changes observed in average numbers of direct flights (DF) and indirect flights (IF) for those routes.

Airports have been grouped according to the results obtained for changes in DF and IF, and ranked according to the total volume of hours saved as a result of Mohring effects.

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[4] Milan and Luxembourg are excluded from this analysis by airport of origin, because due to lack of information routes departing from those two airports are excluded from the sample (although both of them enter as endpoints from routes studied in this work).

Table 6. Mohring effects by airport

Airports	Number of routes	Change in average number of DF	Change in average number of IF	Dt_i* (hours)	Dt_{as}* (hours)	Mohring effect (hours/pax)
London	24	34.5	-18.8	-0.35	-0.01	-0.36
Amsterdam	25	24.8	-13.2	-0.44	-0.30	-0.74
Madrid	24	16.8	-4.0	-0.37	-0.28	-0.65
Frankfurt	19	17.1	-1.4	-0.21	-0.24	-0.45
Vienna	15	18.1	-12.6	-0.63	-0.77	-1.40
Rome	24	17.9	-3.0	-0.30	-0.79	-1.09
Nice	19	10.5	-8.7	-0.33	0.30	-0.03
Geneva	18	7.3	-4.1	-0.38	-0.26	-0.64
Barcelona	25	19.7	-2.4	-0.33	-0.03	-0.36
Paris	23	24.2	0.0	-0.09	-0.30	-0.39
Brussels	15	31.4	0.5	-0.23	-0.32	-0.55
Copenhagen	24	14.6	0.1	-0.13	-0.17	-0.30
Zurich	20	16.0	0.0	-0.35	0.00	-0.35
Manchester	23	8.8	11.4	-0.06	-0.47	-0.53
Munich	21	19.8	17.2	0.16	-0.64	-0.48
Stockholm	12	15.9	33.2	0.24	-1.30	-1.06
Oslo	13	13.2	11.4	0.13	-0.75	-0.62
Dusseldorf	17	14.1	11.0	0.08	-0.37	-0.29
Hanover	16	2.9	18.6	0.29	-1.50	-1.21
Athens	17	-1.3	-13.8	-0.15	0.86	0.71
Lisbon	24	6.3	1.0	0.13	0.29	0.42
Birmingham	18	5.6	-11.4	-0.43	1.35	0.92
Dublin	20	10.0	-28.7	-0.56	1.61	1.05
Helsinki	13	5.8	24.8	0.28	-0.28	0.00

* Simple averages over routes in each group (not weighted by route densities)

The groups of airports considered are the following:

- _Substitution of indirect flights by direct flights_ (London, Amsterdam, Madrid, Frankfurt, Vienna, Rome, Nice, Geneva, Barcelona).

  All these airports, on average, have experienced a reduction in the number of indirect flights and a simultaneous increase in the number of direct connections, for their intra-European routes to destinations included in the sample and all of them exhibit negative values for total Mohring effect ($Dt_i + Dt_{as}$). Most airports in this group are major hubs, but it is also remarkable the presence of some secondary hubs, as Vienna, Nice, Geneva and Barcelona.

- _Increase in the number of direct flights_ (Paris, Brussels, Copenhagen, Zurich)

  These four airports had in 1998 more direct flights on average in their routes than in 1990, while the number of indirect flights remained approximately constant. Their Mohring effects are relatively smaller than those of the first group, explained by the fact that these four airports do not benefit from the substitution effect between direct and indirect flights, which improves travel times t_i.

- Increase of both direct and indirect flights (Manchester, Munich, Stockholm, Oslo, Dusseldorf, Hanover)

  These six airports experienced a global increase in supply for their routes, with the introduction of direct and indirect connections. Average Mohring effects are in line with those of the former groups, being higher for relatively small airports (Hanover and Stockholm exhibit gains per passenger above one hour).

- Positive values for Mohring effects (Athens, Lisbon, Birmingham, Dublin, Helsinki).

  These are the airports which have suffered from the re-organisation of airlines' networks between 1990 and 1998. All of them exhibit positive total Mohring effects – meaning that passengers spent extra times in 1998 compared to 1990– which result from a combination of improvements in travel times (for all of them but Lisbon and Helsinki), and higher values for adjustment-to-schedules times.

  Interestingly, all of these airports are located in the periphery of Europe. This indicates that air markets deregulation has led to a concentration of flight availability in corridors between capitals in the north and middle of Europe, leaving passengers in peripherical airports with lower service levels than in 1990.

5.4 Marginal time savings

Based on the obtained results for Dt_i and Dt_{as}, a final exercise performed is to estimate the relevance of Mohring effects for air transport in marginal terms. The idea is to evaluate what is the impact that an additional passenger on a given route generates for the rest of fellow travellers in that route. For this purpose, a preliminary filtering of routes was performed, to select only those observations with acceptable data on passengers. A sub-sample of 236 routes is used to obtain all results presented in this section.

The analysis of the relationship between the volume of passengers (route density) and the times t_i and t_{as} across the sample routes shows that both magnitudes have quite different patterns. Travel times t_i are basically explained by route length, and density variability does not significantly affect them.

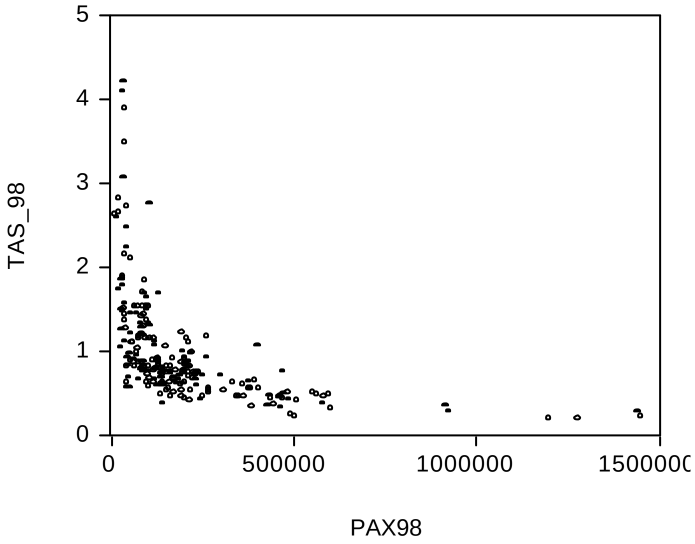
Meanwhile, the volume of passengers is the key variable to explain differences in adjustment-to-schedule times t_{as}. **Figure 4** shows the non-linear relationship between these two variables for 1998 (data for 1990 exhibit a similar form). Given the detected non-linearity, several alternative specifications were explored for the econometric estimation of effects of route density on adjustment-to-schedule times t_{as}. The specification with the best goodness-of-fit is the following:

$$t_{as} = a_0 + \frac{a_1}{q} + \frac{a_2}{q^2} + u \tag{9}$$

where q is the route density (pax per year), u is a random perturbation, and a_0, a_1, a_2 parameters to be estimated.

Expression (9) was satisfactorily estimated with 1998 data, and separately for 1990 data, reaching robust results (see Annex 4).

Figure 4. Relationship between t_{as} (hours) and route density (pax per year)



At the light of the examination of explanatory variables separately for t_i and t_{as} , the specification proposed to analyse Mohring effects in marginal terms is to consider that total time $T = t_i + t_{as}$, depends non-linearly on route density (q) and directly on route distance ($dist$):

$$T = a_0 + \frac{a_1}{q} + \frac{a_2}{q^2} + a_3\ dist + u \tag{10}$$

As in the case of t_{as}, expression (10) was initially estimated with 1998 data, and afterwards with 1990 to check for robustness of estimated parameters. Consistent results were obtained in both cases (see Annex 4).

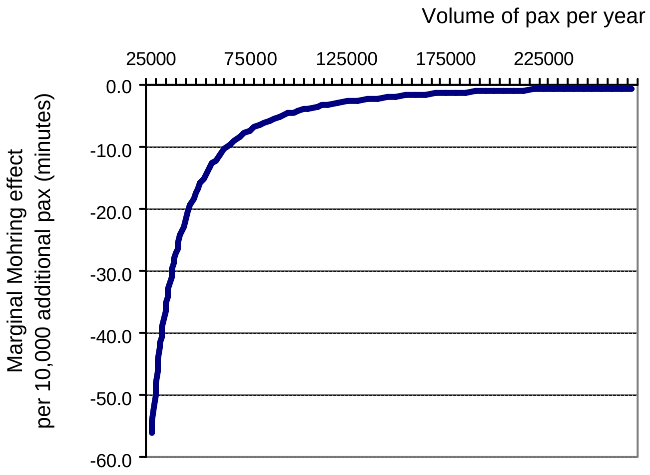
With the values obtained for a_1, a_2, it is feasible to evaluate marginal Mohring effects, simply by taking the first derivative of expression (10):

$$\frac{\partial T}{\partial q} = -\frac{a_1}{q^2} - \frac{2a_2}{q^3} \tag{11}$$

Expression (11) shows the basic result regarding marginal Mohring effects for air transport. The magnitude of these effects depends inversely on the density of the route considered, with a rapid decrease of their importance as routes become denser (indicated by the presence of the terms q^2 and q^3 in the expression). **Figure 5** presents the obtained results.

Some figures can illustrate the magnitude of estimated marginal effects. The entry of 10,000 additional passengers per year in a route with an initial density of 25,000 pax/year would produce a time saving of 56 minutes per passenger (which in monetary terms is equivalent to € 14.51 per pax). If the route density is 50,000 pax per year, the total Mohring effect of the entry of the same additional passengers goes down to 16 minutes (€ 4.14 per pax), and for route densities above 150,000 pax per year, time savings fall below 2 minutes per passenger.

Figure 5: Marginal Mohring effects for air transport



The explanation for the non-linear relationship observed for marginal Mohring effects is quite intuitive. For low density routes, the entry of additional new passengers cause a major impact on the adjustment-to-schedule times of the rest of passengers. In the examples above, the entry of 10,000 additional passengers is not a dramatic increase in weekly demand (around 200 persons per week). This could be accommodated with few additional flights in the route. These new flights, however, may notably improve the situation of passengers who are flying in that route regularly, because the new schedules might better correspond to their preferences about departure times.

For low-density routes, the impact of the additional flights introduced to accommodate the new demand is much more important than in the case of denser routes. For the latter ones, when flight availability is sufficiently wide, the introduction of new flights would be basically irrelevant for existent passengers in terms of adjustment-to-schedule times.

However, in the case of most intra-EU air routes, densities are in the range where Mohring effects are relevant (below 150,000 passengers per year). This explains the magnitude of total effect obtained in this work when evaluating changes between 1990 and 1998 (20.9 million hours), and indicates that in the near future, demand increases for air transport are likely to generate significant positive externalities in terms of time savings for air travellers.

6. Transferability of results

This final section is devoted to discuss the usefulness of the methodology and the results derived from this work, for application to other air corridors not considered in our sample, or even to other transport modes. The objective is to provide a guide for any researcher interested in measuring the type of positive externality observed in transport, and generally known as ‘Mohring effect’.

The first step when trying to evaluate these effects is to have a clear picture of the different components of time spent in the activity of transport. Each transport mode has its own peculiarities, in terms of how passengers access the vehicles (random arrival, tickets bought in advance or in the vehicle, and so forth) and what factors influence the movement of vehicles (road conditions for cars and buses, weather conditions for air and maritime transport, congestion problems for all of them, just to cite a few).

Once these time components are identified, the question to answer is: does the entry of a new passenger have any impact on the time spent by other passengers? The first immediate answer is to think about disutilities for fellow passengers. More time at stops, longer access queues, and less space within the vehicle are probably the main effects that come up when asking that question. However, in all transport modes, there will exist also some potential gains of the type that we have generally termed 'Mohring effects'. Changes in demand induce companies to introduce modification in their levels of service (more frequencies, new vehicles, a wider variety of services, and so forth), which can bring benefits to existent passengers.

The original work of Mohring (1972) concentrated on the reduction of waiting time for passengers at bus stops. This effect would be applicable to any transport mode that shares with buses the characteristic of stochastic arrival of vehicles to pick passengers (taxis, air shuttles, or some kind of continuous ferry services could be included in a list). In order to measure total effects, one would need to estimate the amount of waiting time spent by passengers at stops, and to study the potential reduction caused by an increase of services.

Meanwhile, for transport modes with scheduled departures (trains, boats, planes), waiting times at stops do not have the stochastic component related to the uncertainty about the moment when the vehicle will arrive to the stop. For these modes, there are some unavoidable waiting times required by companies for passengers' boarding, but all those times are programmed in advance. However, there is also an impact caused by the entry of additional passengers, and that is the existence of more options available for travel (new departure times, new types of services). This is the type of positive externality which has been measured in this work for air transport, and that could in principle be applied to any other transport mode with scheduled departures.

For both types of Mohring effects (stochastic or non-stochastic arrival of vehicles to stops), the type of data required to make studies is basically the same. Researchers will need to calculate changes in supply and demand conditions between two periods of reference, therefore it is interesting to try to obtain all relevant information related to services. Frequency of vehicle departures from route heads are generally available from companies (at least for buses), and it provides sufficient data to estimate waiting time for passenger arriving randomly at stops.

For scheduled modes of transport, the source of information to consult is undoubtedly the list of departure times for programmed services. Although delays are a frequent feature in most transport activities, and actual departures may differ from those planned by companies, they can be used as a good proxy.

Based on that information, it is necessary to make some assumptions on preferences of passengers for departure times, in order to assess the amounts of extra time that they have to spend to accommodate their trips to the existent services. Ideally, one could use results from surveys or other direct sources obtaining information from passengers, to determine the volume of passengers wishing to travel at each period of a day or week. In absence of that information (the most frequent case), one can obtain at least some indicative results based on some assumptions on those preferences, as it has been done in this work.

Another type of information required for the evaluation of Mohring effects is that referred to the levels of demand, for the two periods of reference considered for the study. The more complete is the information on total passengers, the better for the assessment on the marginal effects that each additional passenger induces. If data on passengers is not available or of poor quality, it is always possible to refer the effects to modifications in supply conditions (effect of an additional vehicle in the route, or calculation of elasticities of time with respect to supply).

In summary, it can be observed that the methodology proposed in this work can be easily transferable to other contexts, and the type of information required is relatively simple to obtain. It would be interesting to extend the evaluation of Mohring effects to all transport modes, in order to have an idea of the positive externalities present in the activity of transport, and its relative importance for different modes.

Regarding the application of our results derived for the European air sector to other regions, or periods of analysis, the values of time savings obtained indicate that, although the values per passenger might be relatively small on average for dense corridors, the magnitude of Mohring effects is quite substantial for them to be worth studying. Although the figures on total effects are only valid for the particular context where they have been calculated, the marginal analysis presented in section 5 is applicable to other European air routes, even if not included in the sample.

The marginal non-linear relationship found between route density and time savings generated can be considered as robustly estimated. Therefore, the empirical form of expression (11) can be used to estimate marginal Mohring effects for any route, only with information of its density. It must be remarked, however, that results are considered to be valid for European air markets, and should not be immediately transferrable to the context of other world regions.

7. Conclusions

This case study evaluates the existence and magnitude of Mohring effects for air transport within Europe. The context of deregulated markets after 1997 provides an optimal framework to analyse this type of positive externalities that additional passengers create on the rest of fellow travellers. This is so because in more competitive markets, airlines have to react to changes in demand, to avoid being displaced by potential rivals.

Positive externalities created by air travellers are different to those externalities discussed by Mohring (1972) in his seminal paper referred to buses. Increases in bus frequencies raise the welfare of bus passengers, by reducing their waiting times at stops. Meanwhile, passengers of scheduled transport modes, as it is the case of air transport, do no face random arrival of vehicles to stops. However, there are two types of effects similar in nature to the one described by Mohring for buses.

The first one is the reduction in travel time that an average passenger on a given route experiences, when some flights with intermediate stops are substituted by direct connections. Total time spent in the journey then decreases, because connecting flights involve additional take-offs and landings, plus more risk of losing connections due to delays and luggage misplacements. Therefore, when demand of services increase on air corridors, travellers can benefit from the existence of more convenient flights.

The second effect is the reduction of ‘waiting times’ spent due to the need to adjust to flight departure schedules. These times have been termed as ‘adjustment-to-schedule’ times, imposed on passengers by the configuration of airlines’ network. The entry of new passengers on a corridor may have a relevant effect on those times. The introduction of new flights by companies benefits all passengers in the route, who after the change enjoy a situation with more options to accommodate their preferred departure times.

Both types of effects have been evaluated empirically in this work. Results indicate that the magnitude of Mohring effects is quite considerable for air transport. Changes in the schedules of airlines between 1990 and 1998 have created a benefit of 11.4 minutes per passenger on travel times, and 9 minutes on adjustment-to-schedule times. Although these amounts seem small, when evaluated over all passengers represented by the sample using the different routes considered, it is obtained a total global gain of 20.9 million hours.

Average figures represent the situation of European routes as a whole, but in fact mask some patterns detected for different types of routes and airports. The most relevant would be the following:

(i) There is a group of routes (14%) where total number of flights has decreased over the period of reference. This correspond to relatively lengthy routes with low densities. For them, the Mohring effects present positive signs (travel times and adjustment-to-schedule times in fact increase between 1990 and 1998). For these routes, each passenger had to assume a total net effect of more than one extra hour lost.

(ii) A second group is formed of routes where more direct flights have been introduced, and at the same time indirect flights have been eliminated. This is observed for the main airports and routes in the core of Europe (corridors between London and Amsterdam, Brussels, Paris, and Frankfurt), but also in other less dense routes.

(iii) A third group exhibits the opposite trend: less direct flights and more indirect ones. These routes reflect the trend of companies towards the use of hub-and-spoke types of networks, which may or not increase total supply of flights for passengers. The type of route included in this group is relatively long and with a volume of passengers much lower than those in the first group described above (around 40,000 pax per year). On average, travellers in this group have benefited from net Mohring effects, because longer travel times are compensated by a reduction in adjustment-to-schedule times.

(iv) A final fourth group is formed of routes which have benefited from changes introduced by airlines, having both more direct and indirect connections. Mohring effects for them are negative (time savings for passengers).

(v) Regarding airports, the trend is to observe large gains for those cities located close to the centre of the EU, which have the densest corridors (those routes mentioned in part (ii) above). However, given that in 1990 most of them had already good levels of service, they have not been the major winners. Some relatively small airports (compared to those of London, Paris, Amsterdam, or Frankfurt) present gains per passenger close to one hour, adding the improvements in travel and adjustment-to-schedule times. Vienna, Rome, Geneva, Barcelona and Oslo can be cited among the most relevant in a longer list.

(vi) There is another group of airports, located in the periphery of Europe, whose situation is the opposite one. Reductions in services, and the re-configuration of routes towards hub-and-spoke networks have generated time losses for passengers. This is the case of the airports of Athens, Lisbon, Birmingham, Dublin and Helsinki, and the group of low density and lengthy routes already mentioned in part (i).

In order to generalise the obtained results, some non-linear equations have been estimated to evaluate Mohring effects in marginal terms. It has been found that there exists an inverse relationship between Mohring effects and route density, and that these effects are only significant basically for routes with densities below 150,000-200,000 passengers per year.

Above that level, Mohring effects die out rapidly, due to the fact that in denser routes flight availability is sufficiently good for passengers. The additional effect of the introduction of a new departure is then marginally irrelevant, while for low-density routes, it might have a major impact on passengers.

8. References

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Annex 1: Routes included in the sample

To *From*	AMS	ATH	BCN	BIR	BRU	CPH	DUB	DUS	FRA	GVA	HAJ	HEL	LIS	LON	LUX	MAD	MAN	MIL	MUC	NCE	OSL	PAR	ROM	STO	VIE	ZRH		Total routes departing from
AMS	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		25
ATH	1	-	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0		17
BCN	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		25
BIR	1	1	1	-	1	1	1	1	1	1	1	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0		18
BRU	1	1	1	1	-	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0		15
CPH	1	1	1	1	1	-	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		24
DUB	1	1	1	1	1	1	-	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0		20
DUS	1	1	1	1	1	1	1	-	1	0	0	0	1	1	0	1	1	1	1	1	1	1	0	0	0	0		17
FRA	1	0	1	1	1	1	1	0	-	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0		19
GVA	1	1	1	1	1	1	0	0	0	-	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0		18
HAJ	1	1	1	1	1	1	0	0	0	0	-	0	1	1	0	1	1	1	1	1	1	1	1	0	0	0		16
HEL	1	1	0	0	1	1	1	1	1	1	0	-	1	1	1	1	1	0	0	0	0	0	0	0	0	0		13
LIS	1	1	1	0	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1		24
LON	1	1	1	0	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1		24
LUX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0		0
MAD	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1		24
MAN	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	0	1	1		23
MIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0		0
MUC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1	0	0	0	0		21
NCE	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	-	0	0	1	1	0	0		19
OSL	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	0	0	0	-	0	0	0	0	0		13
PAR	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	-	1	1	1	1		23
ROM	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1		24
STO	1	1	1	0	1	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	-	1	1		12
VIE	1	1	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	-	0		15
ZRH	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	0	-		20
Total routes arriving at:	23	22	21	16	20	21	15	16	18	17	13	13	22	22	21	22	20	21	18	19	20	18	17	14	10	10		469

Annex 2: Changes in travel times ($\Delta t_i = t_{i\_98} - t_{i\_90}$)

To

From	AMS	ATH	BCN	BIR	BRU	CPH	DUB	DUS	FRA	GVA	HAJ	HEL	LIS	LON	LUX	MAD	MAN	MIL	MUC	NCE	OSL	PAR	ROM	STO	VIE	ZRH		Average
AMS	-	-1.24	-0.51	-1.28	0.08	0.08	-0.25	0.15	0.07	-0.83	-0.1	-0.75	-0.65	0.01	0.03	-0.62	-1.71	0.35	0.35	-1.74	-0.17	-0.07	-0.83	-0.06	-1.19	0.01		-0.43
ATH	-1.33	-	-1.52	-0.44	-1.14	1.11	-	-	-	-	0.89	0.69	0.05	-0.68	0.39	-0.89	0.75	-0.65	-1.76	0.65	0.77	0.58	-	-	-	-		-0.15
BCN	-0.56	-2.06	-	-1.96	-0.24	-0.62	-0.29	0.28	0.23	1.01	-1.38	-0.56	-0.61	0.73	0.22	0.04	-0.01	-1.19	0.45	0.31	-0.36	0.07	-0.24	-0.9	-1.06	0.54		-0.33
BIR	-0.94	0.6	-1.59	-	-1.31	0.36	-0.02	-0.94	-0.64	-2.1	-0.96	-	-	-	-	0.83	-	-0.76	-0.81	0.55	-0.61	-0.39	0.64	0.33	-	-		-0.43
BRU	0.11	-1.22	-0.37	-1.26	-	-	-	-	-	-	-	-	0.09	0.09	-	-0.16	0.35	-0.36	-0.24	-0.01	0.72	-	-1.2	-	-	-		-0.27
CPH	0.05	0.25	1.11	0.02	-0.5	-	-	0.24	0.06	-1.02	1.28	0.15	-0.02	-0.24	0	0.59	-0.84	-1.04	0.34	-1.96	0.56	-1.16	0.38	-0.01	-1.29	0.06		-0.12
DUB	-0.15	-0.08	-2.48	0.02	-2.13	-0.03	-	-1.72	-1.66	-0.68	-	-	0.69	0.06	0.76	-0.78	0.15	1.6	-0.34	-0.32	-0.27	-1.87	-2	-	-	-		-0.56
DUS	0.01	0.12	0.36	-0.64	0.05	-0.66	-1.96	-	0.46	-	-	-	0.34	-0.2	-	0.46	0.83	1.36	0.75	0.19	-0.02	-0.04	-	-	-	-		0.08
FRA	0.03	-	0.36	-0.96	0.95	-1.16	-0.62	-	-	-	0.08	0.22	-0.07	-0.25	-0.03	-1.25	-0.23	0.07	0.04	-0.94	-0.08	-0.4	0.22	-	-	-		-0.21
GVA	-1.27	-1.30	0.60	-0.79	0.71	0.23	-	-	-	-	-	-	-0.61	-0.62	-1.12	-0.42	0.14	0.23	-0.09	-1.72	-0.07	-0.01	-0.17	-0.6	-	-		-0.38
HAJ	-0.02	-0.36	-0.15	0.16	-0.06	1.59	-	-	-	-	-	-	0.23	1.28	-	-0.76	-0.19	0.48	1.16	0.21	1.72	-0.23	-0.47	-	-	-		0.29
HEL	0.71	1.11	-	-	-0.21	0.71	-0.7	0.32	0.73	0.12	-	-	0.48	-0.21	0.33	-0.01	0.29	-	-	-	-	-	-	-	-	-		0.28
LIS	-0.24	0.21	-1.59	-	0.09	0.45	1.51	0.57	-0.53	0.1	-0.1	-0.02	-	-0.39	0.64	-0.03	0.19	0.22	1	-0.29	2.74	0.01	-0.82	1.28	-1.32	-0.47		0.13
LON	0.02	-1.02	0.07	-	-0.01	-0.28	0.07	-0.34	-0.4	-0.76	0.21	-0.11	-0.31	-	-1.13	-0.24	0	-0.89	-0.16	0.08	0.12	0.06	-0.6	-0.41	-1.39	-0.94		-0.35
LUX	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
MAD	-0.71	-1.13	0.02	0.24	-0.26	-0.69	-	0.71	-1.48	-1.42	-0.66	-0.07	-0.2	-0.71	-0	-	0.34	0.08	-0.13	-1.02	-0.69	0.45	0.17	-0.02	-0.6	-1.18		-0.37
MAN	-1.50	0.78	0.82	-	-0.05	-0.12	0.18	-0.55	0.19	0.42	-0.07	-0.9	-0.17	0.08	0.23	-0.03	-	0.2	0.62	0.2	-0.32	0.65	-0.03	-	-0.88	-1.05		-0.06
MIL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
MUC	0.03	-0.32	1.01	-1.41	-0.06	0.48	0.25	0.87	0.05	1.44	1	0.39	0.85	-0.62	0.22	0.19	-0.3	-1.13	-	-0.85	1.02	0.27	-	-	-	-		0.16
NCE	-1.67	1.12	0.29	-	-0.25	-0.67	1.54	-2.14	-0.19	-1.81	-0.71	0.26	-1.34	-0.16	0.17	-0.82	0.14	0.2	-	-	-	-	0.18	-0.43	-	-		-0.33
OSL	-0.50	1.27	-0.20	0.49	0.13	0.27	-0.11	-0.27	0.14	-1.1	-	-	0.69	0.58	0.34	-	-	-	-	-	-	-	-	-	-	-		0.13
PAR	-0.09	-0.40	-0.34	0.01	-	-0.31	-0.18	0.02	-0.17	0.04	-0.69	0.23	-0.73	0.09	0	0.12	0.48	-0.15	0.01	-	1.25	-	0.19	-0.68	-0.79	0.06		-0.09
ROM	-1.25	0.00	-0.64	-0	-1.2	1.03	-2.21	-1.48	0.3	0.08	-	-0.3	-0.16	-0.35	1.98	0.07	-0.77	-0.07	0.08	0.24	-0.36	0.41	-	-0.62	-2.02	0.08		-0.30
STO	0.39	0.40	2.00	-	0.17	-	-	-	0.14	-0.08	-	-	0.46	-0.26	-0.29	-0.33	-	-	-	-	-	-	-	-	-0.2	0.49		0.24
VIE	-1.36	-0.72	-	-	-	-0.38	-	-	-	-	-	-	-0.76	-1.12	-0.33	-0.38	-1.16	-0.54	0.02	-1.25	-0.66	-1.35	0.08	0.5	-	0		-0.59
ZRH	-0.00	-1.36	0.33	-1.18	-	0.64	-1.86	0.2	0.07	-0.02	-	-	-0.08	-0.6	-1.17	-0.53	-0.89	0.05	-	-0.52	-0.28	0.05	0.03	0.13	-	-		-0.35
Average	-0.45	-0.24	-0.12	-.056	-0.26	0.10	-0.31	-0.26	-0.15	-0.39	-0.09	-0.06	-0.08	-0.16	0.06	-0.23	-0.12	-0.09	0.07	-0.43	0.25	-0.17	-0.26	-0.11	-1.07	-0.22		-0.19

Annex 3: Changes in adjustment-to-schedule times ($\Delta t_{as} = t_{as\_98} - t_{as\_90}$)

To

From	AMS	ATH	BCN	BIR	BRU	CPH	DUB	DUS	FRA	GVA	HAJ	HEL	LIS	LON	LUX	MAD	MAN	MIL	MUC	NCE	OSL	PAR	ROM	STO	VIE	ZRH		Average
AMS	-	-0.36	-1.07	-0.26	-0.60	-0.33	0.12	-1.16	-0.13	0.02	-1.11	0.23	-0.34	-0.02	-0.67	-0.47	0.00	-0.28	-0.95	0.05	-0.24	-0.17	0.03	-0.11	0.32	-0.11		-0.30
ATH	0.21	-	1.58	4.03	0.88	-0.07	-	-	-	-	-0.24	0.44	5.09	0.08	-0.69	0.92	0.23	0.60	0.20	1.26	-0.41	0.49	-	-	-	-		0.86
BCN	-1.14	1.11	-	9.02	-0.57	0.11	0.74	-0.75	-0.42	-0.99	-2.09	-0.42	-1.25	-0.73	-4.01	-0.10	-0.27	0.62	0.37	-2.54	1.26	-0.27	-0.30	0.82	1.38	-0.39		-0.03
BIR	-0.21	4.71	9.25	-	1.49	-0.01	-0.32	0.26	-0.14	5.68	8.23	-	-	-	-	0.39	-	-1.75	-0.11	-0.28	0.27	-0.36	-0.40	-2.35	-	-		1.35
BRU	-0.57	1.18	-1.03	1.91	-	-	-	-	-	-	-	-	-1.50	-0.09	-0.43	-0.53	-1.13	0.02	-0.57	-0.79	-0.96	-	-0.05	-0.22	-	-		-0.32
CPH	-0.46	-0.53	0.08	0.06	-0.28	-	-	-0.70	-0.36	0.14	-1.86	-0.06	0.02	-0.27	-0.93	-0.64	-0.20	0.39	-0.35	3.02	-0.17	-0.05	-0.49	-0.06	-0.30	-0.02		-0.17
DUB	0.33	0.67	2.98	-0.18	-0.09	-0.38	-	1.40	0.24	1.72	-	-	0.67	0.12	-0.63	3.24	-0.11	2.73	2.66	1.87	0.74	0.48	13.79	-	-	-		1.61
DUS	-1.66	-2.62	0.01	0.50	-0.46	0.49	2.14	-	-0.47	-	-	-	-2.11	0.06	-	-0.55	-0.64	-0.90	-0.24	0.56	-0.21	-0.17	-	-	-	-		0.37
FRA	0.00	-	-0.45	-0.14	-0.23	0.21	-0.23	-	-	-	-0.03	-0.50	-1.15	0.03	0.00	0.14	-0.38	-0.17	0.01	-0.20	-0.58	-0.09	-0.75	-	-	-		-0.24
GVA	0.13	0.92	-0.95	8.14	-0.66	-0.12	-	-	-	-	-	-	1.38	-0.04	0.44	-1.04	-1.46	-9.50	-0.84	-0.74	-0.75	-0.04	-0.12	0.50	-	-		-0.26
HAJ	-0.92	-1.36	-1.55	3.26	-2.89	-2.15	-	-	-	-	-	-	-3.35	-0.06	-	-2.11	-3.59	-0.19	-0.29	-0.65	-6.40	-1.16	-0.52	-	-	-		-1.50
HEL	-0.13	-0.54	-	-	-0.35	-0.16	0.11	-0.50	-0.17	-0.02	-	-	-1.44	-0.13	0.09	0.06	-0.49	-	-	-	-	-	-	-	-	-		-0.28
LIS	0.29	3.21	0.30	-	-1.35	1.96	4.83	-1.62	-0.86	0.31	-2.83	1.70	-	-0.12	-2.68	-0.36	-1.81	-0.58	-2.39	9.12	-1.40	-1.31	1.07	-0.64	2.12	0.10		0.29
LON	-0.02	0.48	-0.38	-	-0.10	-0.35	-0.03	0.13	0.01	0.08	-0.05	0.16	0.23	-	0.00	-0.13	-0.14	-0.19	-0.17	0.04	-0.10	0.02	0.21	-0.01	0.09	0.07		-0.01
LUX	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
MAD	-0.89	-0.09	-0.15	1.06	-0.77	0.34	-	-2.61	-0.48	-0.65	-0.25	-0.03	-0.24	-0.05	-1.86	-	-0.10	-0.73	-0.51	0.77	0.34	-0.37	-0.23	0.47	0.91	-0.68		-0.28
MAN	-0.10	-0.25	0.01	-	-1.41	-0.07	-0.06	-0.11	-0.40	-1.21	-2.37	-1.17	-2.09	-0.11	0.91	-0.40	-	-0.31	-0.51	-0.05	0.13	-0.43	-0.02	-	-0.51	-0.18		-0.47
MIL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
MUC	-0.34	-1.17	-0.43	0.18	0.05	-0.17	1.31	-0.27	-0.16	-2.76	-0.47	-0.05	-2.30	-0.33	-1.87	-0.55	-0.74	-0.09	-	-1.25	-1.71	-0.26	-	-	-	-		-0.64
NCE	0.33	-0.57	-2.36	-	-1.88	1.53	20.16	1.85	-2.51	0.17	-2.53	0.48	-4.23	-0.42	1.80	0.03	-0.39	-3.48	-	-	-	-	-2.06	-0.26	-	-		0.30
OSL	-0.27	-1.77	-1.36	0.41	-0.53	-0.19	0.09	-0.31	-0.88	-1.13	-	-	-0.30	-0.54	-2.90	-	-	-	-	-	-	-	-	-	-	-		-0.75
PAR	-0.19	-0.82	-0.29	-0.73	-	-0.25	-0.43	-0.07	-0.23	-0.10	-0.78	0.28	-0.50	0.07	0.11	-0.37	-0.43	-0.11	-0.53	-	-1.04	-	-0.16	-0.02	-0.06	-0.18		-0.30
ROM	-0.45	-0.58	-0.99	0.51	-0.57	-0.36	3.06	-0.31	-0.33	0.03	-	-1.06	-0.23	-0.19	-13.80	-0.27	-1.16	-0.13	-0.85	-3.08	1.91	-0.18	-	0.19	0.54	-0.67		-0.79
STO	-0.21	-1.16	-9.33	-	-0.45	-	-	-	-0.34	0.56	-	-	-1.89	-0.40	-0.51	-1.23	-	-	-	-	-	-	-	-	-0.23	-0.36		-1.30
VIE	-0.12	-1.04	-	-	-	-0.88	-	-	-	-	-	-	-2.20	0.11	-0.62	-2.52	-1.18	-0.53	-0.61	1.12	-0.48	-0.22	-1.10	-1.25	-	-		-0.77
ZRH	-0.27	0.24	-0.93	1.15	-	-0.29	2.78	-0.15	-0.10	0.08	-	-	-0.75	0.01	0.01	0.13	-0.01	-0.13	-	-0.87	-0.29	-0.21	-0.37	-0.11	-	-		0.00
Average	-0.29	-0.02	-0.34	1.62	-0.47	-0.05	2.27	0.10	-0.47	0.04	-0.25	-0.35	-0.73	-0.14	-1.35	-0.29	-0.70	-0.70	-0.31	0.39	-0.50	-0.24	0.50	-0.22	0.43	-0.24		-0.15

Annex 4: Results from econometric estimations

(a)Equations for t_{as} (expression 9 in text)

Estimation Method: Least Squares 1990 Data
Sample: 236 obs.

	Coefficient	Std. Error	t-Statistic	Prob.
α_0	0.590366	0.063066	9.361143	0.0000
α_1	51146.25	5139.321	9.951946	0.0000
α_2	-1.28E+08	69396149	-1.837859	0.0674
Determinant residual covariance		0.279731		

Equation: $t_{as\_90} = \alpha_0 + \alpha_1/(PAX90) + \alpha_2/(PAX90^2)$
Observations: 236

R-squared	0.571413	Mean dependent var	1.299309
Adjusted R-squared	0.567734	S.D. dependent var	0.809604
S.E. of regression	0.532290	Sum squared resid	66.01651
Durbin-Watson stat	1.839900		

Estimation Method: Least Squares 1998 Data
Sample: 236 obs.

	Coefficient	Std. Error	t-Statistic	Prob.
α_0	0.392755	0.050568	7.766919	0.0000
α_1	65637.65	5242.205	12.52100	0.0000
α_2	-4.38E+08	74380171	-5.891113	0.0000
Determinant residual covariance		0.202175		

Equation: $t_{as\_98} = \alpha_0 + \alpha_1/(PAX98) + \alpha_2/(PAX98^2)$
Observations: 236

R-squared	0.518583	Mean dependent var	0.980948
Adjusted R-squared	0.514451	S.D. dependent var	0.649419
S.E. of regression	0.452524	Sum squared resid	47.71331
Durbin-Watson stat	0.915858		

Method: Least Squares Variation 1998/1990 (*)
Sample: 236 obs.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
α_1	-60732.77	7615.775	-7.974601	0.0000
α_2	3.39E+08	79292015	4.281132	0.0000

R-squared	0.127573	Mean dependent var	-0.318361
Adjusted R-squared	0.123845	S.D. dependent var	0.653713
S.E. of regression	0.611895	Akaike info criterion	1.863928
Sum squared resid	87.61336	Schwarz criterion	1.893282
Log likelihood	-217.9435	F-statistic	34.21742
Durbin-Watson stat	1.746337	Prob(F-statistic)	0.000000

(*) Taking differences in equation (9) between 1998 and 1990, parameters α_1 and α_2 can also be estimated from the expression:

$$D\, t_{as} = -a_1 \frac{D\, q}{q_{90}\, q_{98}} - a_2 \frac{D\, q\,(q_{90} + q_{98})}{q_{90}^2\, q_{98}^2}$$

(b) Equations for $T = t_i + t_{as}$ (expression 10 in text)

Estimation Method: Least Squares 1990 Data
Sample: 236 obs.

	Coefficient	Std. Error	t-Statistic	Prob.
α_0	0.987697	0.151674	6.511961	0.0000
α_1	72590.09	9277.323	7.824466	0.0000
α_2	-3.35E+08	1.24E+08	-2.699965	0.0074
α_3	0.002088	0.000128	16.30342	0.0000
Determinant residual covariance		0.842302		

Equation: $t_{as\_90} = \alpha_0 + \alpha_1/(PAX90) + \alpha_2/(PAX90\text{^}2) + \alpha_3$ dist
Observations: 236

R-squared	0.689065	Mean dependent var	4.042625
Adjusted R-squared	0.685044	S.D. dependent var	1.649381
S.E. of regression	0.925648	Sum squared resid	198.7833
Durbin-Watson stat	1.699308		

Estimation Method: Least Squares 1998 Data
Sample: 236 obs.

	Coefficient	Std. Error	t-Statistic	Prob.
α_0	0.801290	0.136844	5.855493	0.0000
α_1	74540.86	10282.30	7.249437	0.0000
α_2	-4.04E+08	1.43E+08	-2.819240	0.0052
α_3	0.001962	0.000119	16.53231	0.0000
Determinant residual covariance		0.719975		

Equation: $t_{as\_90} = \alpha_0 + \alpha_1/(PAX90) + \alpha_2/(PAX90\text{^}2) + \alpha_3$ dist
Observations: 236

R-squared	0.679274	Mean dependent var	3.477520
Adjusted R-squared	0.675127	S.D. dependent var	1.501460
S.E. of regression	0.855797	Sum squared resid	169.9141
Durbin-Watson stat	1.293661		

(c) Estimation of Mohring marginal effects : $D\,T = -\dfrac{745409}{q^2} + \dfrac{4.04\,10^8}{q^3}$

Route density **q** **(passengers)**	**Total Mohring effect** **DT** **(minutes)**	**Adjustment-to-schedule time** **Dt_{as}** **(minutes)**	**Travel time** **Dt_i** **(minutes)**
25,000	-56.0	-46.2	-9.9
50,000	-16.0	-13.7	-2.3
75,000	-7.4	-6.4	-1.0
100,000	-4.2	-3.7	-0.6
150,000	-1.9	-1.7	-0.2
200,000	-1.1	-1.0	-0.1
250,000	-0.7	-0.6	-0.1