Strategic reaction of airlines to the ETS[*]

Estelle Malavolti[†]   Julien Jenvrin[‡]

January 2010

Abstract

   The air transport sector is about to enter the European Trading Scheme progressively in 2011. The regulation of the CO2 emissions means for airlines more costs and a modification of the organization of their market. Our paper proposes a precise model of nonetheless the regulation but also of airlines CO2 emissions. Our conclusions are twofold. Firstly, although profits are negatively impacted by the introduction of the ETS, a monopoly airline carries more passengers at a lower price. Two opposite effects are at play: the marginal cost increases as polluting becomes costly, which results in an increase of the price. However, there is a second effect that makes the price decreasing: the way the free allowances are given creates a bias towards more activity. We show that more activity is reached at the equilibrium. De facto, more CO2 is emitted. Nevertheless, we show as well that it is profitable for the airline to buy a new aircraft because the marginal cost decreased. Again more activity is reached at equilibrium but at the cost of less CO2 emissions.

1 Introduction

The air transport sector in Europe will be fully included in the European Trading Scheme (ETS) in 2012. Despite the relatively low level of greenhouse gas emissions (only 3% of the total European emissions), this sector has known a rapid growth until recently: From 1990 to 2005, the EU aviation emissions increased by 87% and it is expected to double from now to 2020 (See Commission Staff working document 2006 and EU directive 2003/87/EC). On top of this, the air transport sector is also responsible for other releases like nitrogen oxides, water vapor or noise, which effects are not easy to account. Nevertheless, a regulation of these external effects is to be expected. It is thus important to evaluate which impacts a regulation may have on the market and its organization. Our paper offers a precise model of nonetheless the regulation but also of the emissions of the airlines. The regulation system includes two different elements: the first element concerns free allowances that will be given to airlines according to their current activity. The second element is the payment of rights to pollute on the CO2 market. There is a strategic stake in the setting of the "free of charge" quotas, since their number depends on the activity of the airlines: with the system, the airlines will receive a number of rights to pollute proportional to their activity. On the other hand, the rights to pollute, i.e. the internalization of the pollution, will represent an additional cost, which will be higher, the higher the activity. As a consequence we have paid very much attention to the modelization both of the regulation and of the production of emissions. We model the emissions as a joint product of the airlines activity that comes from the utilization of the fuel. Hence a particular attention is given to the estimation of the fuel cost function, which is calibrated with the use of real data. In the economic literature, pollution is modelled as an externality which is not taken into account by the market (see for instance Laffont, 1988). The focus has then been made on the way to "internalize" pollution. Several instruments have been put forward (taxation, subsidies, allowances trading ...) resulting in State intervention, and the literature deeply analyses the efficiency of these different tools (See for instance B. Salani, 2003 or G. Myles, 1995). Our work builds on this general literature focusing on the specificities of the air transport sector to model the impact of an environmental regulation. The environment problems have raised several questions. For instance, Portney (2005) makes a review of the existing regulations and tries to evaluate what will be the regulations of the future. Among the economic tools used to regulate, the taxation is the means which has the most received attention. Barthold (1994) presents the different taxes used for environmental regulation and their efficiency to regulate emissions. We chose to model the ETS as an increase of the variable cost, which means that it can be apparented to a tax (or a subsidy) on the airline activity, because the regulation is designed as such. A particular attention will be given to the study of the use of the fuel by airlines because of its direct relationship with CO2 emissions (See the IPCC report 1999 for an evaluation of the impact of aviation on global atmosphere and the EU Directive 2007/589/EC for the determination of a precise coefficient linking fuel consumption and CO2 emissions). Harris (2005) made an exhaustive analysis of the US airlines operational costs. Miyoshi and Mason (2009) focus on the evaluation of the carbon emissions of airlines. They

propose an original methodology to compute these emissions. We use our own method to evaluate the emission, presented in appendix, but the focus of our paper is more on the economic modelling of the ETS consequences on airlines and their strategies. Besides, we chose to model the externality as a joint production of the airline activity. Models of joint production are presented for instance by Baumgartner et al. (2000, 2003). Our paper is also directly related to papers such as the one by Viera et al. (2007), in which the authors emphisized the importance of having several instruments to reach good result. Our paper propose a more positive view, in examining the current regulation, trying to describe it as close as possible from reality. A paper by Hofer et al. (2009) tries to achieve the same goal with the taxation in the US. However, no economic model is presented in their paper. Finally, our work is complete the work by Albers et al. (2009) and Anger and Kholer which try to evaluate the impact of the ETS on airlines. Again, no economic model is presented which is what our paper brings.

In section 2, we present the European Trading Scheme and how it will be implemented to the air transport sector. A modelisation of this system is then introduced and stylised facts on some financial consequences for airlines are shown. This section ends with the economic model we propose to involve all these elements. In section 3, we derive the results and give interpretations, which proofs are placed in appendix. Section 4 concludes.

2 Modelling the impact of ETS on airlines

2.1 Legislation design and benchmark R

In order to define a model as close to reality as possible, we have to go into the tecnical details of the legislation. This will help us to define the relevant parameters and anticipate if possible, the major impacts of the legiclation on airlines. Airlines will receive at the beginning of each period allowances to emit CO2 and they must surrender at the end of the period the number of allowances equivalent to their total CO2 emissions. To determine the number of allowances given to each airline, the EU will rely on the average level of emissions during the years 2004-2006. The total number of allowances is a sum of three elements: $N_T = N_a + N_r + N_f$, with N_T the total quantity of allowances for a period, N_a the number of allowances to be auctioned for the period, N_r the number of allowances in the special reserve and N_f the number of allowances to be allocated free of charge for the period.. It is worth noting that $N_f = 82\% \times N_T$: Only 82% of the total allowances will be allocated free of charge to the airlines.

2.1.1 Creation of a benchmark

To allocate allowances free of charge to aircraft operators, the EU uses a benchmark. This benchmark is expressed as allowances per tonne-kilometer carried and is calculated by dividing the number of allowances to be allocated free of charge in a period by the sum of the tonne-kilometer data included in applications submitted to the Commission. The use of a measure of the mass multiplied by distance type allows to harmonize the difference of

network between airlines. Let us define W_i as the total tonne.kilometers carried by airline i. Then, $R = \frac{N_f}{\sum_i W_i}$. The number of allowances allocated to the airline i is obtained by multiplying R with the total tonne.kilometers carried by the airlines W_i. The problem is to give a value to R. We consider the airline i, for all its route j covered[1] we define D_j (distance of the route covered by an aircraft, expressed in km) and Q_j (sum of tonnes carried by the airline on the route on the period). Thus, for this route Y_j the tonne.kilometers carried are: $Y_j = Q_j D_j$. The total tonne.kilometers carried of the airline i is $W_i = \sum_j Y_j$. Let us now introduce c_j, the average consumption of fuel, expressed in liter per tonne-kilometers of an aircraft on a given route j. For each route, the average consumption of fuel is equivalent to the fuel consumption divided by the total tonne.kilometer carried. So for each route j, we have information about the couple (c_j, Y_j) and we can compute the total fuel consumption of the airline i as $C_{T_i} = \sum_j c_j Y_j$. Then we define the average consumption per tonne.kilometer of the airline i as $c_{mean_i} = \frac{C_{T_i}}{W_i} = \frac{\sum_j c_j Y_j}{\sum_j Y_j}$. With C_{Total} the total Jet fuel consumption of all the couple (route, aircraft) and all the airlines concerned by the ETS, we can apply the same method and define c_{EU} as the average consumption expressed as liter per tonne-kilometer of all the aircrafts and all the routes concerned by the ETS system $c_{EU} = \frac{C_{Total}}{\sum_i W_i}$. Now let's we introduce the constant λ expressed in T_{CO2}/L which corresponds to the tonnes of C02 emitted by burning one liter of fuel ($\lambda = 2.52^{-3}$ Tonnes/L)

$$R = \frac{N_f}{\sum_i W_i} = \frac{82\% N_T}{\sum_i W_i} = \frac{82\% \lambda C_T}{\sum_i W_i} = \frac{82\% \lambda c_{EU} \times \sum_i W_i}{\sum_i W_i} = \lambda 82\% c_{EU}$$

To understand the consequences, especially financial ones, for the airline i, we have to compute the difference between the real quantity of CO2 emitted expressed in tonnes ($\lambda c_{mean_i} W_i$) and the allowances allocated by the EU to the airline (RW_i):

$$\lambda c_{mean_i} W_i - RW_i = (\lambda c_{mean_i} - R)W_i = \lambda(c_{mean_i} - 82\% c_{EU})W_i$$

2.1.2 The EU choice and the consequences for the airlines

Notice that variable c_{mean_i} is a measure of the fuel efficiency of the airline i. Indeed, the lower the average consumption per tonne.kilometer carried the more efficient the airline. The EU ETS system could have been based only on CO2 emission of each airline and then could have given to the airline a certain percentage of their monitored emissions. But such a system would have rewarded the highest polluter, but not the most efficient one. This would not have been a good incentive for the airlines to be fuel efficient. So the EU system with the benchmark R, based on the tonne.kilometer carried, will reward the efficient airline (i.e. the one with the highest W_i and the best c_{mean_i}). Technically, the EU system relies on the gap between the average consumption of the sector c_{EU} and the average consumption of the particular airline considered c_{mean_i}. Indeed, if $c_{mean_i} > 82\% c_{EU}$, airline i has to acquire allowances. The level of reference $82\% c_{EU}$ thus stands for the standard efficiency level of consumption. The EU compells the airlines to monitor and report, for each route concerned by the ETS, both their tonne.kilometers carried and the CO2 emissions. Indeed, the idea

---

[1]j is a finite number.

is that the total CO2 emissions will be used to design the benchmark R of the next period. The tonne.kilometers carried will be use both to design R and to set the free of charge allocation. What can we guess about the different strategies of airlines with respect to this monitoring/reporting? Like we noted above, according to the ETS, airlines best strategy is to decrease at maximum their consumption c_{mean_i}. Nevertheless, if airline i is big enough, this will also reduce c_{EU}, which is less interesting. Hence big carriers might have less interest in improving their average consumption. However, the maximum gains from a decrease of the average consumption are reached for a no reactions from other airlines (ceteris paribus condition). Suppose every airline is decreasing c_{mean_i}, then the average consumption of the whole sector is decreased and the total impact is not clear cut, i.e., whether improving its system decrease the number of allowances required). Logically, we have the same not clear cut impact about the reported emissions. By reporting "inflated" emissions an airline makes the benchmark R raised (which is a good point) but it has to surrender a higher number of allowances (so, has to buy more allowances on CO2 markets). Concerning the monitored tonne.kilometers, we have a kind of prisoner's dilemma. Indeed, each arline has an interest in "inflating" their tonne.kilometers carried to receive more free allowances. But if all the airlines do that, the benchmark value decreases. So the total impact is ambivalent. However, when an airline is a small one and so has not a great impact on the benchmark value, it is always interesting for it to "inflate" its tonne.kilometer carried and consequently to receive added free allowances.

2.1.3 Stylised facts: financial impact of the ETS on some airlines

The idea of this paper is to evaluate the future impact of the ETS on the airline cost, through the use of an economic model. Several parameters will be at play and induce different impact according to airlines: the fleet (type and age), the network, the type of activity (short-haul, long-haul), the load factor, the flight optimized procedures and the airline strategy. We try to evaluate the impact of the ETS system on somes airlines in terms of cost per 100RPKs (Revenue Passenger Kilometer) considering aircraft operators would pass on most or all of the extra cost to customers. Find such a result is very interesting for two reasons. Firstly the result is more precise than a simple average amount of costs per flight. Secondly such a result enables airlines to be aware about both the real ETS cost for each route and their own efficiency in comparison with competitors. We use the reported CO2 emissions and RPKs of four airlines in 2008 and determine their average consumption per 100RPKs (passenger.100km). We choose the value of the following parameters: c_{EU} (expressed in liters per 100RPKs), λ (expressed in tons of CO2 per liter of fuel) and p_x the allowance price on the CO2 market (with two different working assumptions: 14 euros and 30 euros per ton). Our methodology is to compare the total CO2 emissions in 2008 with the allowances which would have been allocated to the airlines considering their ton.kilometers carried in 2008. Below the data (sources: Carbon Disclosure Projet 2009). We obtain the average fuel consumption per tonne.kilometer by dividing the total fuel consumption per the total RPKs carried.

Airlines performances

Airlines	Rpk000	Emi.2008 (tonnes)	Fuel cons.(liters)	cmean (l/100RPKs)
Easyjet	49077231	4307000	1709126984	3.482
Air France-KLM	162658000	27506144	10915136508	6.710
British airways	115770579	16840627	6682788492	5.772
Iberia	52845795	5839469	2317249603	4.384

Exogeneous data	
$c_{EU\ ETS}$ (l/100RPKs)	5.1
$82\%c_{EU\ ETS}$	4.182
λ (T_{C02}/L)	0.00252
CO2 price p_1	€14
CO2 price p_2	€30

The exogenous value $c_{EU\ ETS}$ is based on the "Global Market Forecast 2009-2028" published by Airbus. Given that this value will be designed by the EU with respect to a certain percentage of the aviation emissions of 2004, 2005, 2006, we choose to take $c_{EU\ ETS} = $ 5.1l/100RPKs. Obviously, all the scheme and its consequences are calibrated by this value.

Extra consumption for airlines

Airlines	Extra cmean (l/100RPKs)	Extra kgCO2/100RPKs
Easyjet	-0.699	-1.762
Air France-KLM	2.528	6.371
British airways	1.590	4.008
Iberia	0.203	0.511

Above we determine the extra c_{mean} expressed as l/100RPKs, which is the difference between the real emissions and the allowances given free of charge. Then, we are able to compute the extra quantity of fuel which is burnt with respect to the EU standard efficiency level of consumption for each passenger carried on 100km.

ETS cost for ailines with carbon price p_1

Airlines	Extra cost in €/100RPKs	Total cost in €
Easyjet	-0.024	-12 111 017
Air France-KLM	0.089	145 098 841
British airways	0.056	64 959 754
Iberia	0.007	3 783 372

ETS cost for ailines with cabon price p_2

Airlines	Extra cost in €/100RPKs	Total cost in €
Easyjet	-0.052	-25 952 180
Air France-KLM	0.191	310 926 088
British airways	0.120	139 199 473
Iberia	0.015	8 107 227

With this computations, taking a CO2 price equal to €14, British Airways ETS cost is about 5.6 cents per passenger carried on 100km. In average for a 1500km flight, the total price will be about €0.84. For a 4500km flight, the total cost will be about €2.52. With a CO2 price equal to €30, the cost per passenger carried on 100km is about to €0.12. The ETS impact becomes more significant again and the need of fuel efficiency crucial. It is worth noting that the average fuel consumption per tonne.kilometer of a short haul flight is always higher than a long haul flight. This is due to the aircraft performance and to the flight procedures. When we compare the real fuel consumption of a long haul flight with the average one of the airline, the extra cost for the long haul travellers is higher than it would be. For the short haul travellers the extra cost is lower. As a consequence, long haul travellers subsidize short haul travellers. Moreover, Easyjet and Iberia are really more efficient than the other airlines. The ETS impact is even positive for the low cost Easyjet. As said before, the ETS impact depends on the fleet (type and age), the network, the type of activity (short-haul, long-haul), the load factor, the flight optimized procedures and the airline strategy. The good performance of Easyjet can for instance be explained by the youth of its fleet and its high load factor, which are easily measurable. The following table synthesizes these two types of information.

Airlines	Age of the fleet (in years)	Load factor (in %)
Easyjet	2.9	84.6%
Air France-KLM	10	79.7%
British airways	11.5	77.4%
Iberia	13	78.8%

Easyjet uses a really recent fleet with high load factors. In comparison Britsh Airways fleet is quite old and its load factor, is in average, 7% lower.

2.2 Economic model

Our model is a model of joint production in which pollution appears as a side effect of the core activity: CO2 emissions exist because airlines operate flights. This assumption is very intuitive and realistic. We will consider the case of an airline which exerts a monopoly position on a particular market. We thus voluntarily put aside the potential competition from other airlines. Our main objective in this paper is to model correctly the regulation and to evaluate the impact of this regulation on a given airline, neglecting first the effect of competition. In a companion paper (Jenvrin and Malavolti (2010)), we introduce competition

and derive the effects of the regulation on competition. The total cost function of the airline is the following:

$$TC(q) = FC + C_F(q) + X(q)$$

FC represent the fixed costs. All administrative costs, labour costs...are included in these fixed costs. $C_F(q)$ stand for the variable costs. To simplify the analysis, we only consider that the production variable costs are coming from the fuel consumption. The main reason is because the emissions are clearly related to the level of fuel consumption. Function C_F depends on the the price of the fuel denoted p_F, which is exogenous and on the quantity of tons carried q, which will be chosen by the airline. We define C_{fuel} as a unit cost, and thus we are able to write

$$C_F(q) = kC_{fuel}(\frac{q}{k}, d),$$

$\forall k > 0$, $\forall q \in [(k-1)q_p, kq_p]$, where d is the distance in km considered (exogenous) and k is an integer and $q \in [0, q_p]$ with q_p parameter modeling the aircraft maximum capacity for passengers (in number of tons). At this stage of the analysis, we need to give a functionnal form for the C_{fuel} function in order to be able to be able to solve analytically the maximization of the profit of the airline. We thus use the following form

$$C_{fuel}(q) = C_0(1 + a)^q$$

with a, a (small) positive constant and C_0, the consumption cost for the route with all the carried staff and stuff but without passenger (the corresponding load factor is thus 0). So C_0 is linked to the basic aircraft consumption, a to the over-consumption due to passenger added (equivalent to mass added). We simplify the shape of $C_{fuel}(q, d)$ using Taylor series and finally obtain[2] :

$$C_{fuel}(q) = C_0(1 + aq + \frac{a^2 q2}{2}).$$

Function $X(q)$ allows to take into account the cost due to the application of the ETS in aviation. X enables to compare the CO2 emissions of the aircraft with the allowances allocated to the airline for the route. Thus,

$$X(q) = (C_F(q)\rho - R\ d\ q)p_x$$

with $C_F(q)$ expressed in euro, ρ, a constant representing the allowance/euro spent for fuel, which depends on the fuel cost and the quantity of CO2 emitted by burning one liter of fuel. R is the benchmark detailed in the previous section and p_x represents the allowance price on the market (exogenous). We consider a linear demand $P(q) = A - Bq$. The variable q represents tonnes of passengers. For the airline industry, it is usually assumed that the typical demand function takes the log-linear shape. In this function the slope changes. At the initial slope, the slope is important in order to model the fact even if the price decrease it is still really high for a majority of potential customers. When the price decreases the quantity demanded becomes greater and greater. In this article we will not present the result for the log-linear demand because the syntaxically hard to present and especially the consequences of the ETS system are the same as with a linear demand.

---

[2] More precision can be found in the appendix 1.

3 Results and consequences on airline strategies

3.1 The impact of the introduction of ETS

The airline chooses the quantity carried (expressed in "passengers in tons") q in order to maximize its profit. We compare this equilibrium solution to the one without any pollution regulation.

Proposition 1 *With a linear demand, the quantity carried by the monopoly airline at the equilibrium is as follows:*

$$q_{eq} = \frac{k(A - aC_0(1 + \rho p_x) + 82\%\lambda c_{EU} d p_x)}{2kB + a^2 C_0(d)(1 + \rho p_x)}$$

The implementation of the ETS entails an increase of the number of passengers carried. The fuel consumption is higher and the airline profits are lower.

Proof.

We have tested the ETS impact on long haul flights, short haul flights, both with linear and log-linear demand functions. We develop below the results but the details of the method can be found in appendix 3. We studied the airline behavior in 3 different situations with different aircrafts (with different efficiency). ∎

Parameters k, C_0 and a measure a technical impact on the equilibrium. Indeed they are all linked to the fuel consumption. They allow to take into account a technical progress that arilines may incorporated to their production system. For instance, if an airline decide to renew its fleet, its fuel consumption will be more efficient since aircraft are new and typically this corresponds to a lower C_0 and/or a lower a. Parameter k links the capacity of an aircraft to its "level of consumption". Indeed, the cost function is defined by steps in order to take into account that the capacity is not continuous. Parameters c_{EU} and p_x measure the impact of the European regulation. A "tougher" regulation would be reflected by a lower mean emission of CO2, i.e. a lower mean average fuel consumption c_{EU} tolerated. Besides, through the quantity of free allowances, the regulator can influence the price of an allowance p_x. A tougher policy would then mean a higher price. Finally, impacts of a change of the demand from passengers are measured through parameters A (maximum of demand) and B (price elasticity): a positive demand choc means a higher A and/or a lower B. The equilibrium quantity is decreasing with the marginal production cost (a and/or C_0), which reflects in our case the efficiency of the aircraft in terms of fuel consumption. It is interesting to notice that if the price of the fuel exogenously increases, the equilibrium quantity decreases since mechanically the cost of producing increases (through C_0). Moreover, if the mean consumption per tonne-kilometer c_{EU} used to design benchmark R increases[3], the marginal cost also decreases. Again the quantity is higher. We show that the regulation leads to an increase of the airline activity, while its profits worsen. What are the effects at play? The introduction of the airline in the ETS means an additional cost: the airline has now to pay for

---

[3]We consider that even in a monopoly on this particular route we consider, our airline fuel consumption effect is negligeable.

its CO2 emissions. This cost is linked to its fuel consumption itself explained by its activity. Hence, a first effect can be identified: to maintain the same level profit, the regulated airline has to reduce its activity, i.e. q_{eq} decreases. This effect is wanted by the regulation since the reduction of activity means as well a reduction of the emissions. However, the regulation itself may induce a higher activity, through function X. Indeed, as the free credits are given as a function of the current activity, airlines have an incentives to increase their activity. More precisely, function X has two opposite effects on q_{eq} : First, consider a situation in which, for each aircraft, the mean fuel consumption per tonne.kilometer carried is upper the "standard efficiency level", i.e. $X(q_{eq}) \geq 0$. As a consequence, the variable cost and thus the marginal cost are higher, which pushes the ticket price upwards, and the number of passengers supplied at the equilibrium downwards. However, the way function X is defined is closely related to the fuel efficiency of the aircraft. And more precisely to the consumption per tonne.kilometer carried of the aircraft, which means that the airline would try to optimize its consumption per tonne.kilometer by optimizing the couple ("consumption","tonne carried"). That's why the load factor raises with the introduction of the ETS. The airline tries to make move closer its own consumption per tonne.kilometer to the "standard efficiency level" $82\%c_{EU}$. Finally, in monopoly position the second effect is more significant and q_{eq} becomes higher. Let us now suppose that the airline owns very fuel efficient aircraft. In this case the tax X would become a subsidy. We simulated it by improving the fuel consumption for the flight and the result is clear. When the aircraft is efficient and when $c \leq 82\%c_{EU}$ the equilibrium quantity increases. As $X(q) \leq 0$, the two above mentionned effects are not opposite anymore: they have the similar positive impact on the supply. Indeed, here X contributes to the decrease of the marginal cost of production. Consequently, in monopoly position when the aircraft is enough fuel efficient and so $X \leq 0$, the impact is clearly to raise the supply. And what if p_x increases? When p_x increases, the need of efficiency is more crucial for the airline. Experimentally, the result is an increase of the equilibrium quantity. The final value of X depends on the parameters.

3.1.1 Investment in a more efficient aircraft

Lemma 1 *Changing of aircraft for a more efficient one leads to a higher number of passengers carried, i.e. q_{eq} is higher, a lower fuel consumption and a higher airline profit.*

Proof.

See in appendix 4. ∎

We consider an airline with a certain aircraft (non-efficient one) which copes with the ETS introduction. We study how the airline faces the legislation by two different cases. The airline keeps its inefficient aircraft compared with the airline removes its aircrafts and invests in a more fuel efficient one. The introduction of the ETS gives the right incentives in terms of renewing the fleet: the profits increase after the change of aircraft, which allows the airline to finance its investment. The gain in efficiency, i.e. the decrease of the production cost has to be sufficient. We show that, even if the airline carries more passengers, the fuel cost and then the total cost depletes.

4 Conclusion

At the beginning of the application, the EU will create an ex-ante benchmark *"so as to ensure that allocation takes place in a manner that provides incentives for reductions in greenhouse gas emissions and energy efficient techniques, by taking account of the most efficient techniques, substitutes, alternative production processes, efficient energy recovery of waste gases, use of biomass and capture and storage of CO2, where such facilities are available, and shall not provide incentives to increase emissions"* [source: European Directive]. Our study reveals the introduction of the ETS system tends to increase the airline activity: more passengers are carried at the equilibrium. This result is due to the particular shape of the ETS cost function X, which we have modelled as closely as possible from the real system. Now, airlines cope with the necessity to improve their load factor and their consumptions per tonne.kilometer. This trend will be emphasized by an increasing allowance price on the CO2 market, which is clearly expected with the entry of many sectors. We can wonder to what extent these results are not opposite to the European Directive aim. The European goal is to deplete the total emissions of the aviation. But here, in monopoly position, we show that the equilibrium number of passengers (q_{eq}) is higher than without regulation. Eventually, more fuel is burnt and consequently more CO2 is emitted. However, our results show that the profits of airlines can be higher if they invest in more efficient aircraft: eventhough the activity would increase, the emissions are lower because of technical progress concerning fuel consumption.

References

[1] Airbus (2009), "Global Market Forecast 2009-2028".

[2] Albers S., J-A.Buhne and H. Peters (2009), "Will the EU-ETS instigate airline network reconfigurations?", Journal of Air Transport Management, Vol. 15, pp 1-6.

[3] Anger, A. and J. Kohler (2010), "Including aviation emissions in the EU ETS: Much ado about nothing? A review", Transport Policy, Vol. 17, pp. 38-46.

[4] Barthold, T. (1994), "Issues in the Desing of environmental Excise Taxes", Journal of Economics Perspectives,Vol. 8, No. 1 (Winter, 1994), pp. 133-151, American Economic Association.

[5] Baumgartner, S., H. Dyckhoff, M. Faber, J. Proops and J. Schiller (2003), " Joint production", International Society for Ecological Economics, Internet Encyclopaedia of Ecological Economics.

[6] JP2 Baumgartner, S. and F. Jost (2000) "Joint Production, Externalities and the Regulation of Production Networks", Environmental and Resource Economics 16: 229-251.

[7] Commission Staff working document (2006), "The inclusion of Aviation in the ETS".

[8] EU Directive (2003) 2003/87/EC, October 2003.

[9] EU Directive (2009) 2007/589/EC, april 2009.

[10] Intergovernmental Panel on Climate Change, "Aviation and the Global Atmosphere", Special report, 1999.

[11] Harris, F. (2005), "An Economic Model of U.S. Airline Operating Expenses", NASA CR-2005-213476.

[12] Hofer, C., M. Dresner and R. Windle (2009), "The environmental effects of airline carbon emissions taxation in the US" Transportation Research Part D, doi: 10.1016/j.trd.2009.07.001.

[13] Laffont J-J. (1988), "Fundamentals of Public Economics", MIT Press.

[14] Miyoshi, C. and K.J. Mason (2009), "The carbon emissions of selected airlines and aircraft types in three geographic markets", Journal of Air Transport Management, Vol. 15, pp. 138-147.

[15] Myles G., (1995), "Public Economics", Cambridge University Press.

[16] Portney, P. (2000), "Environmental Problems and Policy", The Journal of Economic Perspectives, Vol. 14, No. 1 (Winter, 2000), pp. 199-206, American Economic Association.

[17] Salani, B. (2003), "The Economics of Taxation", MIT Press.

[18] Vieira, J., F. Moura and J. Viegas (2007), "Transport policy and environmental impacts: The importance of multi-instrumentality in policy integration", Transport Policy, Vol. 14, pp. 421-432.

A   Appendix 1: Fuel cost function C_F

In this appendix we detail the fuel cost fuel with d as distance of the route, q as tons carried and p_F as fuel price parameter. $C_F(q, d, p_F)$: fuel cost linked to the jet fuel consumption with a given aircraft and a given route expressed as €. To design this function, we define the variables and functions $(F_0(d), C_0(d, p_F), a, q_p)$ which qualify the aircraft characteristics and performances. So each type of aircraft has is own four parameters.

- $F_0(d)$: fuel consumption corresponding to the fuel consumption for the route with all the carried staff and stuff but without passenger (with a load-factor equivalent to 0). This function is a non-linear function, it depends on the type of haul and aircraft and it depends on the variable d, the distance covered. $F_0(d)$ is expressed as liter.

- $C_0(d, p_F)$: consumption cost corresponding to the consumption cost for the route with all the carried staff and stuff but without passenger (with a load-factor equivalent to 0).

$$C_0(d, p_F) = F_0(d) \times p_F$$

Like the function $F_0(d)$, $C_0(d)$ is a non-linear function and depends on the type of haul, the aircraft and the distance covered. $C_0(d)$ is expressed as €. As $C_0(d)$ and $F_0(d)$ are linked with just the constant parameter p_F, for ease of handling we will make appear in formulas in the rest of this part only $C_0(d)$.

- a : parameter modeling the over-consumption due to an added passenger. a is not a function of d, a is a constant without unity.

- q_p : parameter modeling the aircraft capacity for passengers in number of tonnes.

Besides, we define $C_{fuel}(q, d)$ which represents the fuel cost function of the aircraft with $q \in [0, q_p]$. We precise that we have $C_{fuel}(q, d) = F_{fuel}(q, d) \times p_F$ with F_{fuel} the total fuel consumption.

With a given aircraft and its fixed capacity, we can't carry more passengers than the capacity. If $q > q_p$, to carry passengers the airline needs to use several same type of aircrafts or several times the same aircraft (the result is exactly the same). In this model, if the total demand is q and $q > q_p$, the airline must use at least $E[q/q_p] + 1$ aircrafts to transport the passengers ($E[q/q_p]$ is the entire part of q/q_p). We will consider the airline uses exactly $E[q/q_p] + 1$ aircrafts. So eventually we have $E[q/q_p] + 1$ aircrafts with the same load-factor equivalent to $\frac{\frac{q}{E[q/q_p]+1}}{q_p}$.

To determine precisely the shape of the function $C_{fuel}(q, d)$, we used a study realized at the ENAC (Ecole Nationale de l'Aviation Civile) and we have experimentally :

$$C_{fuel}(q, d) = C_0(d) \times (1 + a)^q$$

with $a > 0$ and close to 0.

Physical explication about the shape of C_{fuel}***:*** *when a passenger is added to the flight, the airline need to add fuel because of two physical reasons. Firstly, more passengers*

means more on-board mass (100kg per passenger), so the aircraft mass increases and it needs more power to fly. It means a higher fuel consumption and so, more on-board fuel. Secondly, in aviation, we need to board fuel to transport the necessary fuel for the propulsion. Indeed, because of the fuel mass, the aircraft consumes fuel to transport fuel. These two physical reasons illustrate the shape of C_{fuel}. Moreover, the parameter a is positive but close to 0. Indeed, the experience shows that additional passenger makes the necessary mass-fuel to increase but not tremendously because of the significant aircraft mass alone. We precise in the model we consider a flight without wind and in the standard flight conditions.

At last, the parameters which differentiate two aircrafts with the same capacity are $C_0(d)$ and a. $C_0(d)$ is linked to the basic aircraft consumption, a to the over-consumption due to passenger added (equivalent to mass added). Finally, an airline's fuel cost is a result of two factors : the price of fuel and the fuel efficiency.

In this model, we simplify the shape of $C_{fuel}(q, d)$ using an equivalent. Indeed, as $a > 0$, close to 0 and with $0 < q \le q_p$, we can approximate $(1 + a)^q$ with the Taylor series :

$$(1 + a)^q = 1 + \sum_{i=1}^{n} \frac{1}{i!}(\prod_{j=0}^{i-1}((q - j))a^i) + o(a^i)$$

or

$$(1 + a)^q = 1 + aq + \frac{a^2 q(q - 1)}{2!} + o(a2)$$

Thereby, we choose to use the simplified shape of the cost function with $q \le q_p$:

$$C_{fuel}(q) = C_0 \times (1 + a(1 - \frac{a}{2})q + \frac{a2}{2}q2)$$

But, experimentally we show $a \simeq a(1 - \frac{a}{2})$. Therefore we obtain :

$$C_{fuel}(q, d) = C_0(d) \times (1 + aq + \frac{a^2 q2}{2})$$

The function $C_F(q, d)$ is actually a by part function. In the model, for example if $q \in [q_p, 2q_p]$, $C_F(q, d) = 2 \times C_{fuel}(q/2, d)$. So, we have : $\forall k > 0$ and k whole number, $\forall q \in [(k - 1)q_p, kq_p]$

$$C_F(q, d) = k \times C_{fuel}(\frac{q}{k}, d)$$

A   Appendix 2: Detail of parameters and method

We detail below all the exgeneous values we used in our model. There are two types of constants. Some are linked to the type of aircraft used, some others not. We based our model on a San Fransisco-Paris flight.

Constants unlinked to the type of aircraft

Constant	A	B	λ tons of CO2/liter	p_F fuel price	$\rho = \frac{\lambda}{p_F}$ allowance/€ spent for fuel
Value	5000	60	2.52×10^{-3}	€0.4	0.0063

Constants unlinked to the type of aircraft

Constant	c_{EU} liters per 100RPKs	R allowance/tonne.kilometer	d km	p_x allowance price
Value	4.724	9.9×10^{-4}	6000	€13

Remark : $c_{EU} = 4.724$ *liters/100RPKs, result based on the Airbus estimation of the fuel consumption of word fleet in 2007. We decide to use this value considering a stringent choice of the EU with regards to the aviation. In the simulations we considered passenger+luggage mass equivalent to 100kg and fuel price* $p_F = 0.4$ *€/l the average fuel price for 2009, source IATA (International Air Transport Association).* $p_x = 13$*€, source BlueNext September 2009*

For each of the other constants we base one's value on the experience in order to be realistic. We choose the Paris to San Francisco market with a mono-class aircraft, an Airbus A340-300. We select the capacity of the A340 as $q_p = 27tons$ equivalent to 270 seats. All the experimantal values are extracted from studies realized at the Ecole Nationale de l'Aviation Civile (Toulouse). The real consumption with a load factor equivalent to 0 is about 54.4t, since the fuel density is 0.8, we have :

Constants linked to the type of aircraft

Constant	F_0 liters	$C_0 = p_F \times F_0$ €	a
Value	68000	27200	0.0055

Remark : With 190 passengers boarded the real fuel consumption is 60.5t. With our model we obtain as fuel consumption 60.4t and with our approximated model 60.6t. So our approximation is valid.

In our study of the ETS impact on an airlines which doesn't change its aircraft, we simulate for three aircrafts (ac1, ac2, ac3) with as parameters

Type of aircrafts

Constant	ac1	ac2	ac3
Basis Consumption	C_0	$1.1C_0$	$1.2C_0$
Over-consumption due to an added passenger	a	a	a

Remark : We consider the parameter a (parameter modeling the over-consumption due to an added passenger) is similar for the three aircrafts.

A   Appendix 3: Proposition 1: proof

Profit maximization   We can apply the first and second-order condition to find the optimum of this function for a specific route. "Specific route" means we consider d as a fixed variable and thus we don't try to optimize the function Π with regard to d. We study :

$$\max_q \Pi(q,d) = \max_q P(q)q - TC(q,d) = \max_q P(q)q - FC - C_F(q,d) - X(q,d)$$

As $C_F(q)$ is a by part function equivalent to $k \times C_{fuel}(q/k)$ on the interval $[(k-1)q_p, kq_p]$ with k whole number, we consider :

$$\exists k \geq 0 \quad q_{eq} \in [(k-1)q_p, kq_p]$$

Now we study

$$\frac{\partial \prod(q)}{\partial q} = A - 2Bq - C_0 k\left(\frac{a}{k} + \frac{a^2 q}{k2}\right)(1 + \rho p_x) + Rp_x d = 0$$

$$\frac{\partial 2 \prod(q)}{\partial 2q} = -2B - \frac{a^2 C_0}{k}(1 + \rho p_x) \leq 0$$

As $\rho p_x \geq 0$, $a2 \geq 0$, $C_0 \geq 0$ we have $\frac{\partial 2 \prod(q)}{\partial 2q} \leq 0$, so the second order condition is still checked.

At the optimum, $MR = P(q) + qP'(q) = C'(q)$ with MR : the Marginal Revenue

$$A - 2Bq = C_0 k\left(\frac{a}{k} + \frac{a^2 q}{k2}\right)(1 + \rho p_x) - Rp_x d$$

At the optimum, when $q_{eq} \in [(k-1)q_p, kq_p]$ we have

$$q_{eq} = \frac{k(A - aC_0(1 + \rho p_x) + Rp_x d)}{2kB + a^2 C_0(1 + \rho p_x)}$$

When we introduce the variable c_{moy} with $R_p = 82\%\lambda c_{moy} p_x$, we have

$$q_{eq} = \frac{k(A - aC_0(1 + \rho p_x) + 82\%\lambda c_{EU} d p_x)}{2kB + a^2 C_0(1 + \rho p_x)}$$

Airline before and after the ETS system :   We consider three different airlines with three different aircrafts. We observe always the same phenomenon: the implementation of the ETS entails an increase of the number of passengers carried. The fuel consumption is higher and the airline profits are lower.

Results with an airline before and after the ETS system

	aircraft ac1	aircraft ac2	aircraft ac3
$\triangle\, q_{eq}$ tonnes	0,87	0,86	0,85
$\triangle\, C_F(q_{eq})$ e	145	158	169
$\triangle\, X(q_{eq})$ e	185	700	1134
$\triangle\, C_T(q_{eq})$ e	251	777	1303
$\triangle\, P(q_{eq})$ e	-52	-51	-51
$\triangle\, \Pi(q_{eq})$ e	-153	-665	-1177
$\triangle\, c(q_{eq})$ l/t.km	-0,01	-0,01	-0,01
$\triangle$ Load factor(q_{eq})	0,02	0,02	0,02

A Appendix 4: Proposition 2: proof

Airline before and after the ETS with a more efficient aircraft :   We compare the two following situations: - An airline with the aircraft $ac2$ which changes its aircraft with introduction of the ETS system - An airline with the aircraft $ac2$ which doesn't change its aircraft with introduction of the ETS system We observe: changing of aircraft for a more efficient one leads to a higher number of passengers carried, i.e. q_{eq} is higher, a lower fuel consumption and a higher airline profit.

Results with an airline before and after the ETS system with a more efficient aircraft

	ac1 with ETS - ac2 without ETS	ac2 with ETS - ac2 without ETS
$\triangle q_{eq}$ tonnes	1	0,86
$\triangle C_F(q_{eq})$ \$	-5905	158
$\triangle X(q_{eq})$ e	251	620
$\triangle C_T(q_{eq})$ e	-5800	777
$\triangle P(q_{eq})$ e	-61	-51
$\triangle \Pi(q_{eq})$ e	5921	-665
$\triangle c(q_{eq})$ l/t.km	-0,05	-0,01
$\triangle$ Load factor(q_{eq})	0,02	0,02