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Strategic reactions of airlines to the European trading scheme

Estelle Malavoltia,∗ Marion Podestab

a TSE(ENAC), 7 av. ed Belin, 31055 Toulouse cedex 4, France
b Université de Savoie (IREGE), 4 chemin de Bellevue, 74000 Annecy-le-vieux, France.

Abstract

The air transport sector entered the European Trading Scheme in 2012 (for the intra-European flights). The regulation of CO2 emissions is costly for airlines and modifies the organization of their market. Our paper proposes an economic analysis in which the regulation but also CO2 emissions of airlines are modelled. We show that, in a perfect competition setting, the difference between passengers carried without regulation and when the regulation is put in place, is negative for the best-performing planes. However, for the less efficient aircraft, the implementation of the regulation entails a reduction of airlines activity, and therefore a low level of carbon emissions.

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1. Introduction

Since the Kyoto Protocol in 1997, several governments have made significant progress toward improving air quality. In this sense, the air transport sector in Europe will be fully included in the European Union Emissions Trading Scheme (EU-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

∗ Corresponding author. Tel.: +33-562259609; fax:+33-562174017.
E-mail address: estelle.malavolti@enac.fr
The environmental literature defines pollution as an externality which is not taken into account by the market. Several instruments have been put forward (taxation, subsidies, norms or allowances trading) resulting in State intervention, and the literature deeply analyzes the efficiency of these different tools (see for instance Myles, 1995 or Salanié, 2003). 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.

The European Commission has included the aviation sector in the EU-ETS in 2012 in relation to the airlines' carbon emissions. The aim of carbon markets is to provide incentives to reduce CO2 emissions. The environmental problems have raised several questions. Scheelhaase and Grimme (2007) focus on financial impacts to include aviation in the ETS on airlines. They show that the financial impact on airlines subject to the ETS is relatively moderate. Since the regulation concerns all flights departing from and arriving at EU airports, Scheelhaase and al. (2010), under a model-based empirical estimations, analyze how the EU directive affects competition between European and non-European airlines and if competition distortions are likely to appear. They compute fuel consumption, CO2 emissions and number of allowances to know the difference between allowances allocated free of charge and the total amount of them needed by the airlines (with a price assumed to 20€ per ton of CO2 and two scenarios considered for emissions growth). Moreover, regarding consumers' surplus, they show that the impact on prices is relatively moderate.

On an macro-economic view, Anger (2010) shows that there is not expected to have a negative impact of the EU-ETS on economic growth in the UE or to reduce the UE's competitiveness relative to the rest of the world. However concerning the impact of EU-ETS on the carbon emissions, the results are ambiguous. Mayor and Tol (2007) find a negative impact on the carbon emissions whereas Anger (2010) concludes in a positive way. It seems difficult to have an economic model which combine the regulation of EU-ETS, the financial impact on airlines and the level of carbon emissions.

In this sense, we build an economic model which offers a precise framework of nonetheless the regulation but also of emissions of 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 this 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 use of the fuel. Models of joint production are presented for instance by Baumgartner et al. (2000, 2003). Hence a particular attention is given to the estimation of the fuel cost function, which is calibrated using real data. We chose to model the EU-ETS as an increase of the variable cost, which means that it can be similar to a tax (or a subsidy) on the airline activity, because the regulation is designed as such. A particular attention is 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) makes 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. They distinguish between short, medium and long hauls and they take into account the load factor, however in our paper we model it. Therefore, we use our method to evaluate the emission, but the contribution of our paper is more on the economic modelling of the EU-ETS consequences on airlines and therefore on their strategies. Our paper is also directly related to papers such as Viera et al. (2007), in which the authors emphasized the importance of having several instruments to reach efficient result. By focusing on the current regulation and trying to describe it as close as possible from the reality, we propose a more positive view. Hofer et al. (2009) try to reach the same aim with the taxation in the US, however no economic model is presented in their paper. Finally, our model is the extension of the
paper of Albers et al. (2009) and Anger and Kholer (2010) which try to evaluate the impact of the EU-ETS on airlines. Again, no economic model is presented in this literature. We focus on the regulation of CO2 in EU and try to model it as faithful to reality as possible, the following section presents the system of European Union Emissions Trading Scheme. In section 2, we introduce a model of the EU-ETS system. This section ends with the computation of an equilibrium in which we derive the results and give interpretations. The following section shows examples of the use of our model. We present some concluding remarks in a final section.

2. The Model

2.1. CO2 Emissions trading scheme in the European Union

The European Union Emissions Trading Scheme (EU-ETS), created in 2003 (EC, 2003) and implemented in 2005, is the first international trading system for carbon dioxide (CO2) emissions in the world. The aim of carbon markets is to provide incentives to reduce CO2 emissions. This system was implementable between European countries under several measures. Allocation is a unique feature of cap-and-trade systems. Indeed, a critical issue in dealing with climate change is deciding who has a right to emit carbon dioxide (CO2), under what conditions, and to what extent those emissions are limited. The EU-ETS is the first instance of creating explicit rights to emit CO2 and distributing these rights among sub-national entities. One of the main measures in the EU-ETS is to provide free allowances. The cap for these free allowances in the aviation sector will be limited to 97% of an annual rate of reference from 2012 and this limit will be restricted to 95% from the period 2013 to 2020.

Moreover, the system was able to take advantage of the experience of the United States in the field of the acid rains. The US's success with sulphur dioxide emissions trading provides to European economists insights to apply to the European situation and provides to, in the Member States and the Commission, a body of literature and individual experiences to learn from. The EU-ETS program was divided into two phases, a pilot phase (2005-07) and a second or Kyoto phase (2008-12) to ensure a quality program.

The allocation methodologies applied by the 25/27 participating nations were remarkably similar. Four choices seem particularly interesting:

- Auctioning was only little used. One of the most striking features in the EU allocation process was that most Member States chose not to take advantage of the Directive's provision allowing states to auction up to 5% of allowances in Phase I and 10% in Phase II.
- Strong reliance on recent historical emissions. The disparity between advocacy and practice was in no aspect greater than for benchmarking. Benchmarking was strongly advocated however little used, which is a striking difference from US practice.
- Expected shortage was allocated to the power sector. Another distinctive feature in the EU allocation process was that the power sector was compelled to bear almost the entirety of the emissions reduction burden. When a Member state was short on allowances, this shortage was almost entirely allocated to the power sector.
- Highly novel new entrant/closure provisions. All Member States have set up reserves for new entrants, and most require closed facilities to forfeit post-closure allowances, even though there are significant differences between the specific Member State choices.

The first lessons of the pilot phase are that the European Commission has harmonized allocation rules across Member States and has tightened the carbon constraint in Phase II. Moreover, free allocation does not necessarily lead to windfall profits and first studies, as presented in the next section, show that the increase of costs due to CO2 regulation affect consumers' price but firms do not put the total cost on prices. Finally, new entrant/closure provisions provided perverse incentives. Indeed, the main effect of these provisions was to preserve pre-policy incentives to invest in polluting technology.

Concerning the quantity of allowances exchanged, these quantities in 2005 were relatively low at 262 Mt. Trades increased nearly fourfold by 2006, when 809 Mt were exchanged. The maturation of the market was confirmed in 2007, when almost 1 500 Mt were traded. These transactions are made with an average price of € 22 per ton in 2005, therefore the allowance transactions totaled € 5.97 billion during the year. This total increased to €15.2 billion in 2006 before reaching € 24.1 billion in 2007.
Once quantities exchanged are estimated, the EU allowance (EUA) price can be fixed. This price is determined by the equilibrium between supply and demand. Between the phase I and II, EUA price tends to decrease nearly to zero due to surplus saved on the period 2005-2007. Phase I allowance prices' fell under 1 € /tCO2 in February 2007 and ended 2007 at 0.02 €/tCO2. Finally, the EUA prices for 2008-2012 remain stable and reach a peak at €25.

Therefore, the collapse of the first period carbon price has not jeopardized the expansion of the trading scheme. This is probably one of the most impressive results of this first trial period: all the big industrial and financial partners now accept that carbon is no longer free in Europe and that the carbon emissions will continue to be costly in the future.

Finally, concerning the level of carbon emissions, we can conclude that a modest amount of abatement occurred in 2005-2006. In a preliminary but detailed analysis of this data, Ellerman and Buchner (2010) concluded that a reasonable estimate of the reduction in CO2 emissions attributable to the EU-ETS lies between 50 and 100 Mt for each year, or between 2.5% and 5% what emissions would have been without the EU-ETS.

The EU-ETS system is the first carbon market and is now implementable in the aviation sector. To know how is the impact of this regulation on the airlines, consumers' surplus or CO2 emissions, we model the behavior of the different stakeholders.

### 2.2. The Emission Trading Scheme regulation

Airlines are responsible for externalities such as pollution (NOx, CO2, noise...) congestion and accidents. These externalities have social costs which differ from individual costs. For instance, the air transport sector produces CO2 emissions while the Society would prefer a lower level of these emissions. The levels of production of CO2 differ because the air transport sector is producing CO2 at a zero cost while the Society values negatively the emissions of CO2. The Society would be willing to pay to reduce the level of CO2 emissions. The problem is that the market failed to take into account the social costs and finally, a public intervention is needed because the right level of production is not reached. The economic literature suggests different instruments like norms or emission quotas (regulation in quantity) or taxes or subsidies (regulation in prices) to consider social costs (as pollution). The European Commission has chosen to create a market for pollution in order to make firms buy the rights to pollute. This market for allowances is thus used to regulate the CO2 emissions. The principle is simple: The regulator sets a maximum quantity of CO2 emissions tolerated by the Society for a given period (generally a year) and firms exchange rights to pollute. On this market, there will be firms from different sectors, sectors which pollute and thus have to buy for their emissions and sectors which receive rights because they pollute less than what they are entitled to emit. Airlines will be included in the European cap-and-trade system starting 2012, only for intra-European flights but we extend the analysis to other situations (like long-haul trips) since the ICAO has decided to put in place a general system for 2016. They thus will have to pay for their CO2 emissions and follow a certain path in terms of reduction of their CO2 emissions. The principle of the regulation is to give part of the total emissions of a given airline for free and to let it buy on a market the rights to pollute for the other part of its emissions. As it is costly, one expects airlines to take measures to reduce their emissions. 85% of the allowances will be given for free. The EU defined a benchmark of emissions which corresponds to the average of the emissions calculated for the period 2004 to 2006. The target of the regulation is then to reduce the emissions with respect to this average level by 3% for the year 2012 and by 5% beyond 2012. The CO2 emissions are depending directly on airlines activity: the more activity, the more they have to pay. It is thus important to define precisely a measure of the activity of the airlines. The indicator which we choose as relevant is a weight and distance indicator. Indeed the CO2 emissions depends proportionally on the quantity of fuel used. This quantity itself is sensitive to the distance covered together with the weight carried. Therefore the relevant measure is expressed in tons times kilometers. Let us define $W_i$ as the activity of airline $i$ expressed in tons.km (one passenger with his luggage stands for 100kg) during a given time period (typically one year). Airline $i$ will thus receive a share of its yearly activity $RW_i$ for free, where $R$ is defined as follows $R = \tau \lambda c_{ETS}$, where $\tau$ is the target of reduction of the regulator. It equals 0.97*0.85 for the year 2012 and 0.95*0.85 beyond 2012. $\lambda$ is a constant which represents the tons of CO2 emitted by burning one liter of fuel. It equals $2.52 * 10^{-3}$ tons of CO2/l. We define $c_{ETS}$ as the average consumption of fuel (expressed in liters of fuel per ton.km) for the benchmark period 2004-2006. $R$ is thus the benchmark used by the regulator to set up the emissions it authorizes for a given period. $R$ is constant for all the airlines. Their emissions rights are adapted with respect to their activity $W_i$. As a consequence, each airline $i$ has to buy exactly
\[ \lambda W_i (c_i - rc_{ETS}) \] allowances, where \( c_i \) corresponds to its average consumption of liters of fuel per tons kilometers over the given period. The average consumption of fuel is computed as follows, for airline \( i \), which operates \( J \) routes

\[ c_i = \frac{\text{cons of fuel for all } J \text{ routes}}{\sum_{j} W_{ij}} \]

The number of allowances asked to each airline relies on the efficiency of the airline. Indeed, it is not only relying on the activity of the airlines, which would have pushed airlines to increase their activity. The allocation also depends on the distance between the average fuel consumption of the airline and the benchmark chosen by the ETS, which is calculated over all the airlines for the period 2004-2006. If airline \( i \) is more efficient than the benchmark, which means that its fuel consumption is lower than the average consumption, airline \( i \) receives allowances which will be sold on the market. On the contrary, if the airline fuel consumption level is higher than the benchmark, airline \( i \) has to buy allowances. At this stage, the number of allowances depends also on the global activity of the airline, which creates a leverage effect. The cost of the emissions of an inefficient airline which operates a lot will be very high. These costs will result in adjustments for airlines in terms of technical progress or different strategies. Indeed, the renewal of the fleet, the modernization of the equipment, the optimization of the planes' trajectories, as well as the reorganization of the network, the reallocation of the planes are the different actions an airline can take.

### 2.3. The Airline cost function

The regulation of the CO2 emissions means additional costs for airlines. These costs are related to their activity because of the regulation itself and because the regulation is associated to their fuel consumption. Hence, the relevant costs to be taken into account are the variable costs. There are several variable costs to be considered like labour costs, fuel costs, maintenance... depending on the time horizon considered (annual or infra-annual). One important element of these last years is the fuel consumption cost. Indeed, it has increased from 10% in 1994 of the total operating costs to 33% in 2008 (Source: AEA and EIA forecasts). The air transport sector is also well known for the importance of its fixed costs, like the investment in planes, like administrative costs (to develop a network) or marketing costs. The fixed costs occur in the decision of launching an activity or entering a new market. Once incurred, what matters to determine firms strategies are the variable costs. In our economic model we will consider only variable costs and analyze the impact of the regulation on the determination of airlines activity: will they carry more or less passengers? according to which strategies? how will they modify their network?

The total costs function of the economic model is composed of three parts: the fixed costs, the variable costs concerning the fuel consumption and the variable costs due to the regulation. Let us define:

\[ TC_i(q_i, d_i) = FC_i + C_{F,i}(q_i, d_i) + X_i(q_i, d_i) \]

where \( FC_i \) represents the fixed costs, \( C_{F,i}(q_i, d_i) \) is the total fuel cost of airline \( i \) and \( X_i(q_i, d_i) \) is the emissions cost of airline \( i \). The activity of the airline is a combination of the tons carried, denoted \( q_i \), and the expanse of the network, denoted \( d_i \) for airline \( i \).

At first, fixed costs are normalized to zero for each airline because we consider the situation of an airline which has its own network. Fixed costs will be reintroduced to consider the decision to extend a network or even maintain a given route afterwards. The economic model aims to show how the current activity of airlines is impacted by the new regulation.

As we focus on the regulation and its financial impact, we restrict our attention to the sole variable costs which are directly related to the regulation itself, i.e. the fuel costs. The fuel costs are depending on the price of the fuel \( d_F \) which is given on the crude oil spot market. It increased continuously since 1994 to 2008 and now is more stable, due to the world recession. Nonetheless this price is structurally going to raise again because of non-renewable resources and increasing world demand, putting pressure on airlines for a better use of the kerozen. The other two parameters which determine the fuel costs, are the expanse of the network which expressed as a distance variable denoted \( d_N \), and the activity on a network measured by the number of passengers carried expressed in tons, \( q_i \).

Over a network, the fuel consumption is not homogeneous. Indeed, for a given route, the take-off is
the phase of time which consumes more fuel. Differences also exist with respect to the distance of a given route: a long haul flight uses less fuel than a short haul flight per ton km. One reason is technical: as the take-off phase consumes more, it can be less amortized if the flight is short. Moreover, on a long haul flight, it is easier to optimize the fuel consumption as the cruise phase is longer. We have chosen to focus on the problem of capacity. Indeed, the airline supply on a given network is not fully adjustable because of the given capacity of aircraft. For instance if an airline owns 2 planes of equal capacity, let say 100 passengers for each, if the demand is 90 then only one plane is needed and the load factor is 90%. However if demand is 110, then the airline has to put one other plane and the load factor decreases drastically (110/200=55%). This has to be taken into account in the costs and especially in the fuel costs since there is a certain amount of fuel to be carried to fly with a zero mass (when the plane is empty) and the marginal cost of carrying one more passenger is also increasing since more power is needed to carry a higher mass. 

We thus choose the following functional form to represent the cost function:

$$C_{F_{t, i}}(q_t, d_t) = kC_{fuel, i}\left(\frac{q_t}{r}, d_t\right).$$  (1)

where $q_t$ is the activity of airline $i$ (in tons carried), and $k$ is an integer, $d_t$ is the scope of the network. This function is defined for all $(k - 1)q_p < q \leq kq_p$, where $q_p$ stands for the maximum seats offered for one plane (we assume that the fleet is composed of homogeneous planes of equal maximum capacity measured in tons). The total fuel cost is thus a piecewisely function, increasing in $q_t$. The fuel cost function is also increasing with the km covered $d_t$. Besides we define: $C_{fuel, i}(q_t, d_t) = C_0(d_t)(1 + a)^{q_t}$, where $C_0(d_t)$ represents the minimum cost to be supported if one plane is used. It corresponds to the consumption cost for the route with all the carried staff and cargo but without passenger, on a given distance $d_t$. $a$ is an efficiency measure of the aircraft fuel consumption. It corresponds to the fuel consumed for one passenger added in the plane. $a$ is assumed to be small and can be checked empirically. We assume besides that the whole influence of parameter $d_t$ is captured in $C_0(d_t)$ and will use several values of this parameter to calibrate the model. For sake of simplicity, we use a Taylor series development and will use the following function:

$$C_{fuel, i}(q_t, d_t) = p_F F_0(d_t) \left(1 + aq_t + \frac{a^2q_t^2}{2}\right).$$  (2)

$X_i(q_t, d_t)$ allows to take into account the cost due to the regulation of the ETS in aviation. This function is built in order to measure the additional cost incurred by the regulation. This cost depends on the activity and on the fuel consumption. It is in fact a measure of the distance between the emissions of the airline on the route expressed as a function of the fuel consumption and the emissions tolerated by the regulator, which we introduced in the previous section. The average fuel consumption of airliner $i$, for a given network, is thus $C_i = \frac{\sum_{i} C_{F_{t, i}}}{d_{i, F}}$ and the regulation cost can thus be defined as follows:

$$X(q_t, d_t) = p_a \left(\frac{\sum_{i} C_{F_{t, i}}(q_t, d_t)}{p_F} - Rq_t d_t\right)$$  (3)

where $p_a$ is the price of an allowance in the market. Airlines are price taker, they do not have any influence on it. $p_F$ is the price of the fuel, given on the market, $R$ equals $r\lambda_{ETS}$ as defined in the previous section. $X(.)$ can be positive or negative depending on whether the airline has a fuel consumption respectively above or below the benchmark. If the spot price of the emission rights $p_a$ is higher, the costs of the regulation becomes more important if the airline has to buy rights. The airlines have thus an interest in forecasting properly the price of the allowances. The two instruments of the regulator to set a certain level of $R$ are the target coefficient, $r$ which is supposed to decrease over the years and the benchmark evaluation of the fuel consumption of airlines. If the price of the fuel $p_F$ is higher, then the $X(.)$ function is less likely to be positive. Indeed, a low fuel price relaxes the constraint of being more efficient in using fuel. If the fuel costs are higher, then the costs of the regulation are also higher. It means that a less efficient firm will support higher costs for the regulation of its emissions. Eventually, if the activity of the airline increases, then the fuel costs increase but the free allowances as well. There is a trade-off between increase of the fuel cost and free allowances, and the problem for the airlines is if the fuel costs increase at a higher rate than the activity.
3. Strategic reaction of airlines

We first analyse a situation in which airlines are competing à la Bertrand on a given city pair. This means that parameter $d$ is exogenously given. Firms are then price takers and their goods are perfect substitutes for consumers. The maximization program is thus

$$\text{Max} \pi(q) = pq - \left( FC + C_F(q) + X(q) \right)$$

The first order conditions give

$$p = \frac{\delta C_F(q)}{\delta q} + \frac{\delta X(q)}{\delta q}$$

The airlines equalize what selling one ticket (or pricing one additional ton carried) yields to what it costs at the margin, i.e. the supplementary fuel consumption needed to carry this additional passenger (or ton) plus the additional regulation cost (if the carrier is less efficient than the average) or minus the benefit (if the carrier is more efficient than the average). Taking into account the definition of function $X(.)$, the expression writes:

$$p = \left( 1 + \frac{p_a}{p_F} \right) \frac{\delta C_F(q)}{\delta q} - R$$

This equation corresponds to the supply of each (identical) airline. The demand is assumed to be linear. Note that the demand is linear to make the model more tractable, but results are robust to a log-linear shape of the demand:

$$p = A - Bq,$$

where $A$ and $B$ are positive. $A$ corresponds to the willingness to pay of consumers, i.e. it corresponds to the maximum price consumers want to pay for a given network (it can be not only an origin-destination but an aggregate network). This maximum price is increasing with the scope of the network. We do have typically very few information on the value of this parameter. Some airlines run surveys in order to learn about this value. However the information is quite difficult to estimate. $B$ is a measure of the sensitivity of the variation of the price to a variation of the quantity. It is a very important parameter for the airline because while choosing a quantity to supply (or equally a price to fix), $B$ is a measure of what reduction in the price is needed to attract one more passenger. We make the assumption that demand is influenced by the distance parameter through $A$ and consider that the consumer’s reaction to a modification of the price is not influenced directly by the destination chosen. More precisely, it means that the willingness to pay for a trip from Paris to San Francisco is assumed to be higher than the one for a Paris-Madrid. However, the sensitivity to the price is kept constant.

The equilibrium quantity is then

$$q^{eq} = \frac{k(A-aF_0(p_F+p_a\lambda)+c_{ETS}dpa\tau\lambda)}{(Bk+a^2F_0p_F+a^2F_0p_a\lambda)}$$

The quantity at the equilibrium depends on different sets of parameters. The first set of parameters includes technical variables, like $k$, $F_0$ and $a$. These parameters are linked to the technical efficiency in using fuel and capacity of the airline. Hence, they allow to take into account the technical progress that airlines may incorporate into their production process. For instance when an airline decides to renew a plane, both coefficient $F_0$ and $a$ are modified to take into account a more efficient fuel consumption. Parameter $k$ changes to take into account both the change in capacity and the induced modification of the load factor. The regulation levers are the price of an allowance $p_a$, the average consumption $c_{ETS}$ used as benchmark and the target $r$. A strict regulation will be for instance a higher price of allowances, induced by a lower quantity of emissions rights decided by the European Commission. It also corresponds to a lower cap set $r$. Even though the regulator cannot play with all the instruments at the same horizon, it is still interesting to analyze the impact of a variation of the different parameters. Indeed, $r$ is fixed till 2020 by the law and $c_{ETS}$ is computed according to the past activity of airlines. However, the price of allowances $p_a$ can be decided on a year basis. Finally, parameters $A$ and $B$ influence the demand and therefore the choice of equilibrium. For instance a
positive demand shock would translate into a higher $A$ (maximum of demand). Parameter $B$ measures the sensitivity to a variation of the quantity of the variation of the price. The more sensitive the consumers' demand, the lower the ability of the airline to set a higher price at equilibrium. If the airline chooses a more efficient plane with a lower $F_0$, the number of passengers carried at the equilibrium is higher. More activity is reached due to a better use of fuel. Coefficient $a$ plays in the same direction as well: a lower $a$ means a higher efficiency which enables the airline to carry more passengers. When the capacity of the plane $k$ is increased, the quantity is increased at the equilibrium to take into account the cost of a having a "bad" load factor. A more stringent regulation resulting in an increase of the price of allowances $p_a$ leads to a lower activity for the airline. If the average fuel consumption $c_{ETS}$ decreases, the quantity decreases as well at the equilibrium. The effect of the target $r$ plays in the same direction: if the regulator decides to strengthen the regulation (lower $r$), then the impact on the quantity is negative and less passengers are carried at the equilibrium. The price of the fuel has the same impact in our model than the price of an allowance: the higher the fuel price, the less the quantity. It is important to note that in our model, a partial taxation of the fuel price would have the same kind of effect than the ETS system. If demand increases, for example with a higher $A$, then the quantity at the equilibrium increases. If demand is less sensitive to the price, the airline is then able to set a higher price for the same quantity or to increase the quantity at the same price. Finally, $d$ stands for the distance of the destination considered or more generally the scope of the network of a given airline. Parameter $d$ has an influence on the choice of parameter $F_0$ because every type of plane will not be able to operate every destination. Without regulation, the airline program is the following:

$$\text{Max}\pi(q) = pq - (FC + C_F(q))$$

The solution of this program offers an interesting benchmark to evaluate formally the impact of the regulation on the activity. After computation, the solution is:

$$q^{PCN} = \frac{k(A-aF_0p_F)}{(Bk+a^2F_0p_F)}$$  \hspace{1cm} (6)

**Proposition:** The regulation can have a positive impact on the activity of the airlines. The effect depends on the parameters.

Proof: we compute the difference between the quantities with regulation and without regulation. This difference is

$$q^{PCN} - q^{PC} = \frac{k p_a \lambda (aBF_0k - Bc_{ETS}dkr + a^2F_0(A - c_{ETS}dp_r))}{(Bk + a^2F_0p_F)(Bk + a^2F_0(p_F + p_a\lambda))}$$

The denominator is always positive, for all acceptable values of the parameters, thus the sign depends only on

$$(aBF_0k - Bc_{ETS}dkr + a^2F_0(A - c_{ETS}dp_r))$$

Note that this expression is not depending on the price of the allowances. On the contrary, it depends on the price of the fuel which has a negative impact on the difference. Indeed, an increase of the price of the fuel has more influence on the quantity without the regulation, it decreases faster. The technical parameters ($a$ and $F_0$) are more likely to have a negative impact: if the plane chosen is less efficient (higher $a$ and or $F_0$) then the difference is positive. Finally, if the regulation is less strict (higher benchmark $c_{ETS}$ and or higher target $r$) the difference is more likely to be negative, since the quantity with regulation increases, while the other quantity is not impacted. We cannot say much more since there are too many parameters in the model. To go further we have to specify more and explore the relationship between these parameters. This is what we do in the following section. [end of proof]

Whether to know if the quantity of equilibrium is lower in case of regulation is not fully trivial. It is not clear whether this quantity is lower or higher to the quantity with regulation since the ETS can be either a cost or a benefit for the airlines. The regulation has been set in order to limit the CO2 emissions, which leads, if no technical progress is incorporated or simply available, to a direct decrease in the activity of the airlines. This result is thus all the more counterintuitive. However, it is due to the design of the regulation, which induces airlines to increase their activity in
order to cover the cost of the regulation. Finally, results depend on the parameters values and we take several examples to illustrate the situation. They are presented in the following section.

4. Applications

The first parameters we set are the regulation, the price of the allowances and the price of the fuel (Table 1). The other parameters we have described (technical, demand) are not completely independent of the distance parameter which is considered as exogenous in this model. Indeed, on a long haul trip, the plane chosen will have different technical characteristics ($F_0$ and $a$) than on a short haul. The plane is typically larger when the distance is higher, which goes with a higher 'fixed' consumption of fuel i.e. with a zero load factor (higher $F_0$) and with a lower marginal consumption of fuel (lower $a$). For the moment, we cannot give a functional form to model the influence of the distance on the technical characteristics. We thus chose to distinguish two cases: a long haul trip, with a given distance and evaluate for what pair of technical parameters $(a, F_0)$ the quantity with regulation is higher. Moreover, the demand is also influenced by the distance because the willingness to pay for a long trip will be higher than for a short trip. For this reason, we decide to examine two opposite cases: the first situation corresponds to a long haul flight, the second to a rather short haul flight.

| Parameter | Value |
|-----------|-------|
| $e_{ETS}$ | 0.4724/RTK |
| $r$ | 0.8075 |
| $\lambda$ | 0.00252 t(CO2)/l |
| $p_r$ | €13 |
| $p_a$ | €0.4/l |

4.1. Long-Haul Scenario

The distance between Paris and San Francisco is 9000km, thus we set $d = 9000$. The demand function is defined for a one way trip. It is the residual demand, given all the other costs especially variable costs (cabin crew, maintenance, catering...), thus the maximum demand is lower than the one addressed to the company (our simulations are however robust to a large range of maximum demand and elasticity. We tried to make the examples as realistic as possible though. The simulations files are available upon request). We chose to set $A = 8000k$. Parameter $k$ intervenes since the demand is defined by plane. $k$ represents the number of planes used at the equilibrium to carry the optimal number of passengers and cargo, the maximum demand has thus to be multiplied by $k$ to be homogenous. For simplicity, we set $k = 1$.

We chose to take two values for the sensitivity of the demand to the price. We consider first a demand which is rather inelastic, i.e. $B_1 = 0.8$. We then consider a rather elastic demand $B_2 = 1.2$.

Lemma: The regulation leads to more activity when the airlines use efficient airplane. For instance, for an elastic demand, $B_2 = 1.2$, the equation gives:

$$q^{PCN} - q^{PC} \geq 0 \iff F_0 \geq \frac{2746.53}{0.8a + 6626.73a^2}$$

Figure 1 illustrates this situation. Results are robust to the assumption of inelastic demand.
For example, if the airlines use a A340 to operate the route Paris-San Francisco, the technical characteristics are: $(F_0 = 68000, \alpha = 0.0055)$. Then the difference is positive: the airlines reduce their activity due to the regulation.

4.2. Short-Haul Scenario

Let us now set $d=1300$. The corresponding maximum demand is lower than for the long haul trip, around €500 per ton km, thus $A=500$ k. For simplicity, we present only the case for which $k=1$. Both situations, elastic demand and inelastic demand are analyzed, but we present the results for an elastic demand, since results are consistent with an inelastic demand.

Lemma: The regulation leads to more activity when the airlines use efficient airplane. For instance, for an elastic demand, i.e. $B_2=1.2$, the equation gives

$$q^{P_{CN}} - q^{P_{C}} > 0 \iff F_0 > \frac{396.722}{0.8\alpha + 301.639\alpha^2}$$

Figure 2 illustrates this situation.
5. 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 economic analysis shows that the introduction of the ETS system tends to increase the airlines activity for the more efficient aircraft: more passengers are carried at the equilibrium. This result is due to the particular shape of the ETS cost function, 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 consumption per ton-kilometer. However, for all less efficient aircraft, the introduction of the regulation tends to decrease the airlines' activity and therefore to reduce the greenhouse gas emissions.

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